Mobility Model based on Shortest Distance assumption and Location Update Optimization in PCS

Dissertation submitted to Jawaharlal Nehru University in partial fulfilment
Of the requirements for the award of the degree of

Master of Technology

in

Computer Science & Technology

By

RATNA SEKHAR POTINENI

SCHOOL OF COMPUTER AND SYSTEMS SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI 110 067

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जवाहरलाल नेहरू विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI - 110 067

CERTIFICATE

This is to certify that the dissertation entitled **"Mobility Model based on Shortest Distance assumption and Location Update Optimization in PCS "** being submitted by **Ratna Sekhar Potineni** to the School of Computer and Systems Sciences, **Jawaharlal Nehru University, New Delhi** in partial fulfilment of the requirements for the award of the degree of **Master of Technology** in **Computer Science & Technology.** The work presented in this dissertation has not been submitted for the award of any degree or diploma.

Ratna Sekhar. P.
Ratna Sekhar Potineni
(Student)

Prof. Karmeshu
Supervisor
SC&SS
Jawaharlal Nehru University
New Delhi – 110 067

C P Katti
Prof. C.P. Katti
Dean
SC&SS
Jawaharlal Nehru University
New Delhi – 110 067

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RATNA SEKHAR POTINENI

Dedicated to

... my Beloving parents and family members

Abstract

In the present day communications the users, the services available to users are mobile in nature. In order to consider these issues, the concept of Mobile Networks comes into picture. Mobile Networks accommodate broad range of services with different mobility characteristics. It is therefore essential to understand the mobility and its effects on communication systems. As an aid to achieve this efficiency, we have developed modelling aspects related to the mobility characteristics of users to optimize the Location Updating (*LU*) cost. For optimization of this *LU* cost service area has been divided into Location Registration (*LR*) areas.

This dissertation work consists of four chapters. The first chapter explains the concept behind the cellular communications. It provides the basic concepts such as call processing, mobility management, and radio resource management. Second chapter deals with the idea about the location tracking and various paging strategies in the *LR* area design. Location tracking is the main concept in the mobility management and it also facilitates the tracking of user in the network. Third chapter presents the modelling aspects of mobile users in the two-dimensional grid architecture. In this architecture the *MS* can move in eight directions from any cell. Using this architecture we have derived an algorithm which calculates the probability of moving to any cell in the *LR* area from the starting *LU* cell in *n* steps i.e., $\Pr(v(i,j)/n)$. Based on this algorithm we have also given equation for optimum number of cells in the *LR* area i.e., N_k. $\Pr(v(i,j)/n)$ and N_k are useful in the Optimization problem which we have discussed in the fourth chapter. We have also given an algorithm for the design of the *LR* area based on greedy method. Finally we have compared the performance results obtained for different approaches in the design of the *LR* area.

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Chapter 1

Introduction

(1.1) Personal Communication Services

Personal Communication Services (PCS) is an integration of existing wireless and wired communication networking capabilities, this will allow communication with *MS* (mobile subscriber) regardless of their location [1]. Wireless Personal Communications has become one of the key emerging technologies. Which is the fastest growing segment of the telecommunications industry. Personal Communications Services (PCS), a family of telecommunications services, support personal, handset, and service mobility. PCS standardization has become a complex process involving many organizations, industry associations and government agencies interacting one way or another [2]. The majority of activity is in the area of air interface, inter-system signaling, mobility management, and network management [3].

The provision of sophisticated services to mobile users becoming increasingly important. To provide these services the concept of Cellular Network comes into picture. Cellular Networks have experienced a tremendous growth in the field of telecommunications. This results in rapid growth in the population of mobile subscribers, and thus increasing the total signaling in wireless networks [4]. Increased signaling incurs additional cost to the system by requiring more network resources for control functions, which could otherwise be used for voice traffic [6]. The load on other functions of the network such as databases and switching in the fixed network also increases. Among the others radio bandwidth is considered the more scarce resource. It is therefore desirable to design wireless networks which make efficient use of the limited radio bandwidth. Accordingly the effective mobility management schemes emerges as an important means to achieve such efficiency.

(i) Problem formulation: In the present scenario the provision for a wider range of sophisticated services to mobile users in increasingly important. The voice service will remain to be the largest portion of the service to be offered. The demand for more advanced services like video and data services is growing enormously. In the context of wireless telecommunication system the two important concepts are:

(a) Location Updating: This strategy holds whenever the *MS* (Mobile Subscriber) moves out of the vicinity of the *LR* (location registration) area. In location updating *MS* has to informs to the *MSC* (mobile switching center) about his mobility characteristics so that the contact can be established in the future reference [4].

(b) Paging: In this strategy whenever an incoming call comes for the *MS* it has to be sent to *MS* correctly i.e., to communicate with the mobile user, system has to be locate the user for the call which is to be routed successfully. In order to locate the *MS* calls are paged in the LR (location Registration) area. Some earlier systems used to page the unit over all the cells in the service area. In this case there is only one location area and it is the service area itself. Such strategy requires substantial radio bandwidth. In cellular systems, the air interface is considered to be the scarce resource. Instead of paging over all cells, there is a mechanism in which the user informs the system about its location according to some registration rule. In this way, when an incoming call arrives, the system may select a subset of the cells in which the mobile is most likely to roam and page the user in only those cells.

Study of paging and updating shows the tradeoff relationship. It may be noted that if the number of cells in a LR area is more, then the cost of paging will be maximum where as no registration or updating is required. If the number of cells in a LR area is less, then the cost of paging will be minimum but the cost of updating or registration will be maximum [4]. For some particular partitioning of the service area, the total cost of paging and registration will be minimum. The cost function is the sum of cost components resulting from paging signaling and updating or registration signaling. We would like to obtain an optimum partitioning to minimize the cost of updating or registration by keeping the paging cost constraint as constant [4]. In the design of the LR area the cost associated with updating and paging as formulated by Abutaleb and Li [4] is given by

$$C(x) = C_p(x) + C_u(x) \qquad (1)$$

$$= k\mu_a\, C_p + \mu_k C_\mu \qquad (2)$$

where k is the number of cells in the *LR* area , μ_a is the arrival rate of incoming calls for the *MS* (calls/ unit time), C_p is the paging cost per cell(bandwidth/ cell), μ_k is update rate for *MS* in *LR* area containing k cells (upd/ unit time) and C_μ is the cost for a *LU* (bandwidth/upd).

(1.2) Cellular Mobile Communication principles

Cellular Mobile communications is one of the fastest growing and most demanding one in the present day circumstances [2]. It is expected that cellular systems using a digital technology will become the universal method of telecommunications. The concept of cellular service is the use of low-power transmitters where frequencies can be reused within a geographic area [2]. The idea of cell-based mobile radio service has been formulated at Bell Labs in the early 1970s, Cellular systems began in the United States with the release of the advanced mobile phone service (AMPS) system in 1983. In the early 1980s, most mobile telephone systems were analog rather than digital One challenge facing analog systems was the inability to handle the growing capacity needs in a cost-efficient manner. As a result, digital technology got a big boost. The advantages of digital systems over analog systems include various facilities like ease of signaling, lower levels of interference, integration of transmission and switching, and increased ability to meet capacity demands [2].

(1.3) Cellular system architecture & concepts

A Cellular system can maintain number of Mobile users within a base station area. The cellular communications system consists of the following four major components [2].
1.Public switched telephone network (PSTN): PSTN is made up of local networks, the exchange area networks, and the long-haul network that interconnect telephones and other communication devices on a worldwide basis.
2.Mobile telephone switching office (MTSO): The MTSO is the central office for mobile switching. It houses the mobile switching center (MSC), which is useful for maintaining database of all the MS regarding their mobility characteristics [3].
3.Cell site with antenna: The term cell site is used to refer to the physical location of radio equipment that provides coverage within a cell. A list of hardware located at a cell site includes power sources, interface equipment, radio frequency transmitters and receivers, and antenna systems [2].
4.Mobile subscriber unit (MSU): The mobile subscriber unit consists of a control unit and a transceiver that transmits and receives radio transmissions to and from a cell site. Three types of MSU's are available:

1. Mobile telephone
2. Portable
3. Transportable

Mobile telephone is installed in the trunk of a car, and the handset is installed in a convenient location for the driver. Portable and Transportable telephones are hand-held and can be used anywhere. The use of Portable and Transportable telephones is limited to the charge life of the internal battery [6] .

A cellular mobile communications system uses number of low power transmitters to create cells. A variable power level of the transmitters allows the cells to be sized according to the MS (mobile subscriber) density and demand within a particular BS (base station) area. Channels (frequencies) used in one cell can be reused in another cell some distance away. Cells can be added to accommodate growth of the *MS*, creating new cells in unserved areas or overlaying cells in existing areas [2]. Each mobile uses a separate, temporary radio channel to talk to the cell site. The cell site talks to many mobiles at once, using one channel per mobile. Channels use a pair of frequencies for communication-one frequency, the forward link, and one frequency, the reverse link. Mobile users stay near the base station to maintain communications properly because the radio energy dissipates over distance. The basic structure of mobile networks includes telephone systems and radio services. In situation where mobile radio service operates in a closed network and has no access to the telephone system, mobile telephone service allows interconnection to the telephone network as depicted in Figure 1.

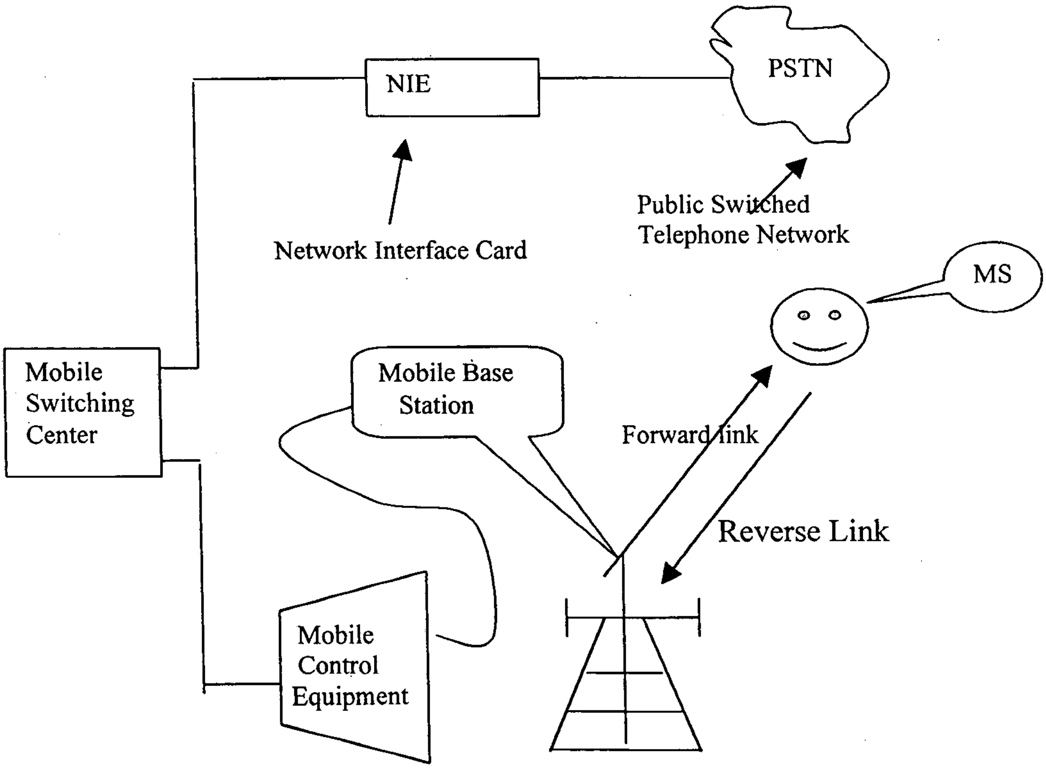


Figure 1. Mobile Telephone network service

Interference problem: If the same channel is used in adjacent base station areas then interference problems may occur. This shows that we cannot reuse all the channels in adjacent base stations. Areas have to be skipped before the same channel could be reused. Researchers discovered that the interference effects were not due to the distance between areas, but to the ratio of the distance between areas to the transmitter power (radius) of the areas [2] . By reducing the radius of an area by fifty percent, service providers could increase the number of potential customers in an area by fourfold. Accordingly systems based on areas with a one-kilometer radius would have one hundred times more channels than systems with areas ten kilometers in radius. This shows that by reducing the radius of areas to a few hundred meters, millions of calls could be served. The cellular concept uses variable low-power levels, which allows cells to be sized according to the subscriber density and demand of a given area [2]. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells.

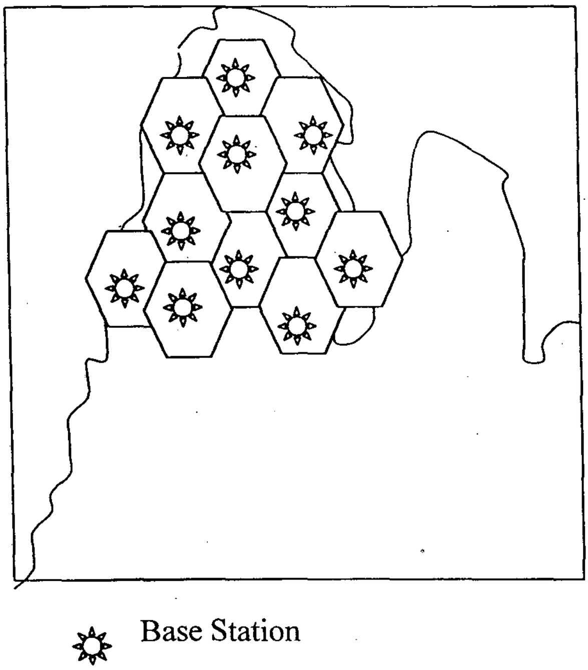


Figure 2. Mobile Telephone System Using a Cellular

Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between cells as shown in Figure 2. The base station can communicate with mobiles as long as they are within range. As radio energy dissipates over distance, so the mobiles must be within the operating range of the base station. Like the early mobile radio system, the base station communicates with mobiles via a channel. The channel is made of two frequencies, one for transmitting to the base station and one to receive information from the base station

Cellular system architecture

As a result of increase in demand and the poor quality of existing service forced mobile service providers to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular use was limited, efficient use of the required frequencies was needed for mobile cellular coverage. In modern cellular telephony, rural and urban regions are divided into areas according to specific guidelines.

Cells: A cell is the basic geographic unit of a cellular system. Cells are base stations transmitting over some geographic regions that are represented as hexagons. Each cell size varies depending on the location, terrain and radio propagation characteristics. Because of constraints imposed by natural terrain and man-made structures, the true shape of cells is not a perfect hexagon.

Clusters: A cluster is a group of cells. No channels are reused within a cluster. Figure (3) illustrates a seven-cell cluster.

Frequency Reuse: Because only a small number of radio channel frequencies are available for mobile systems, there is a need to find a way to reuse radio channels in order to carry more than one conversation at a time. The solution adopted was called frequency planning or frequency reuse. Frequency reuse was implemented by restructuring the mobile telephone system architecture into the cellular concept. The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned a group of channels that is completely different from neighboring cells. The coverage areas of cells are called the footprint. Which is limited by a boundary so that the same group of channels can be used in different cells that are far enough away from each other so that their frequencies do not interfere.

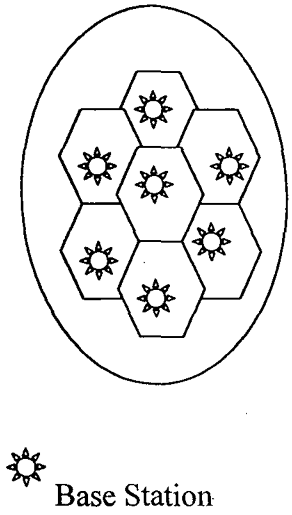


Figure 3: Cluster size expressed in number of cells

Cell Splitting: Economic considerations made the concept of creating full systems with many small areas impractical. To overcome this difficulty, system operators developed the idea of cell splitting. As a service area becomes full of users, this approach is used to split a single area into smaller ones.

Handoff: A significant aspect in the development of the cellular network involves the problem created when a mobile subscriber moves from one cell to another during a call. As adjacent areas do not use the same radio channels, a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells. Because dropping the call is unacceptable, the process of handoff was created. Handoff occurs when the mobile telephone network automatically transfers a call from one portion of radio network to the adjacent portion of the radio network as the *MS* crosses adjacent cells.

(1.4) GSM network architecture:

Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard, the group would formulate specifications for a mobile cellular radio system operating at 900 MHz [2].

The GSM Network

The GSM network is divided into seven parts [7]

(i) Switching System (SS)
(ii) Base Station System (BSS)
(iii) Operation and Support System (OSS).
(iv) Message Center (MXN)
(v) Message Service Node (MSN)
(vi) Gateway Mobile services Switching Center (GMSC)
(vii) GSM Interworking unit (GIWU)

The basic GSM network elements are shown in Figure 4.

(i) The Switching System

The Switching System looks into mobile user related functions such as looking into matters like Incoming and outgoing calls of each user. The switching system includes the following functional units [7]

(a) Home location register (HLR)
(b) Mobile switching center (MSC)
(c) Visitor location register (VLR)
(d) Authentication center (AUC)
(e) Equipment identity register (EIR)

(a) HLR: It is considered the most important database, as it stores permanent data about each and every MS, including a subscriber's service profile, location, information, and activity status. It is used for storage and management of subscriptions. When an individual buys a subscription from one of the PCS operators he or she is registered in the HLR of that operator.

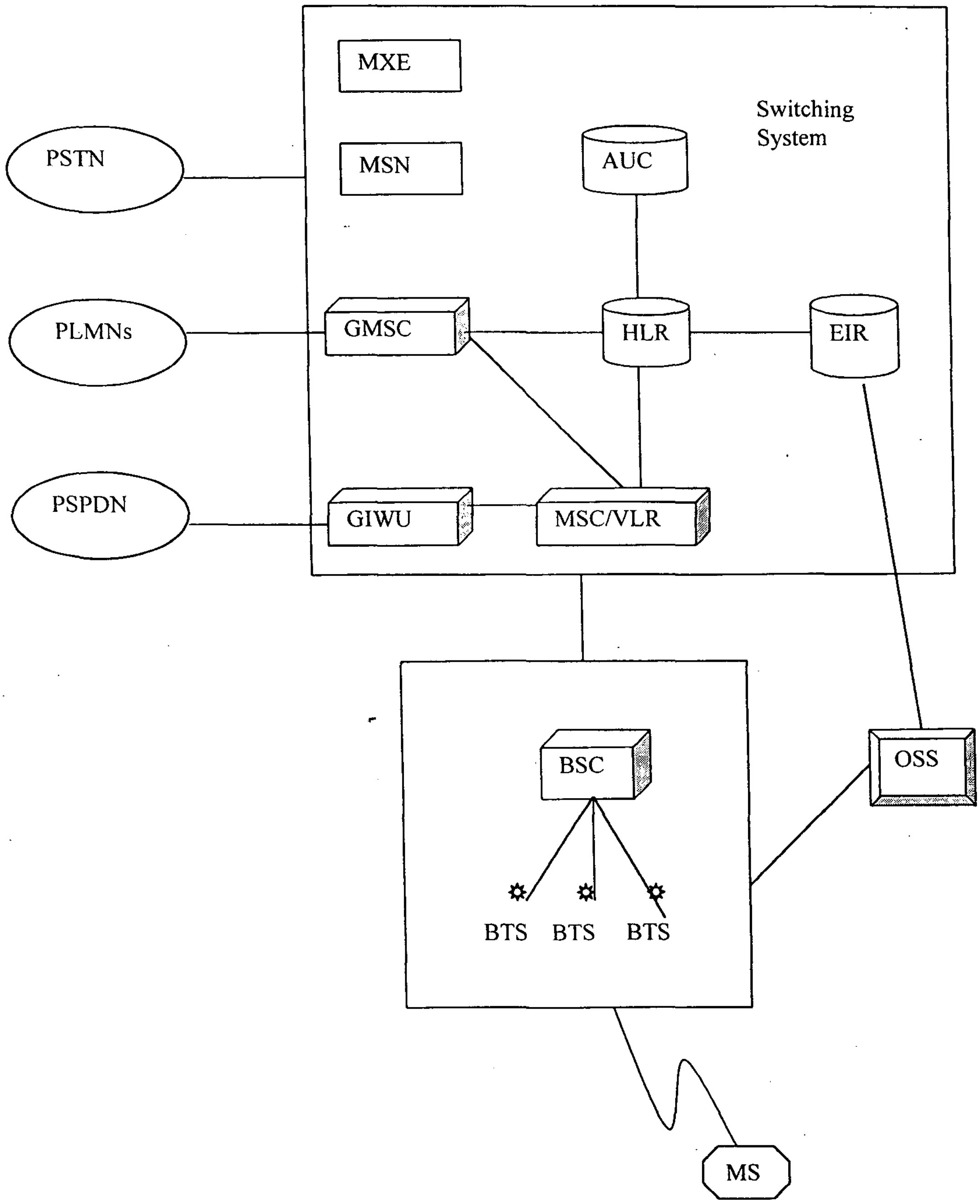


Figure 4. GSM Network Elements

(b) MSC: It performs the telephony switching functions of the system. It controls calls to and from other telephone and data systems. It also performs such functions as toll ticketing, network interfacing, common channel signaling, and others.

(c) VLR: It is a database that contains temporary information about subscribers that is needed by the MSC in order to service visiting subscribers. The VLR is always integrated with the MSC. When a mobile station roams into a new MSC area, the VLR connected to that MSC and will request data about the mobile station from the HLR. Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogating the HLR each time.

(d) AUC: It provides authentication and encryption parameters that verify the user's identity and ensure the confidentiality of each call. The AUC protects network operators from different types of fraud found in today's cellular world.

(e) EIR: It is a database that contains information about the identity of mobile equipment that prevents calls from stolen, unauthorized, or defective mobile stations. The AUC and EIR are implemented as stand-alone nodes or as a combined AUC/EIR node.

(ii) Base Station System (BSS)

This BSS considers matters related to transmission such as radio-related functions. Which consists of [7]

(a) Base Station Controllers (BSC)
(b) Base Transceiver Stations (BTS).

(a) BSC: It provides all the control functions and physical links between the MSC and BTS. It is a high-capacity switch that provides functions such as hand over, cell configuration data, and control of radio frequency (RF) power levels in base transceiver stations. A number of BSCs are served by an MSC.

(b) BTS: It handles the radio interface to the mobile station. The BTS is the radio equipment (transceivers and antennas) needed to service each cell in the network. Groups of BTSs are controlled by a BSC.

(iii) Operation and Support System

The operations and maintenance center (OMC) is connected to all equipment in the switching system and to the Base Station Controllers. The implementation of OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional, and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organizations.

(iv) Message Center

The MXE is a node that provides integrated voice, fax, and data messaging. Specifically, the MXE handles short message service, cell broadcast, voice mail, fax mail, e-mail, and notification.

(iii) Message Service Node

MSN is the node that handles the mobile intelligent network (IN) service

(i) Gateway Mobile Services Switching Center

A gateway is a node used to interconnect two networks. The gateway is often implemented in an MSC. The MSC is then referred to as the GMSC.

(v) GSM Internetworking Unit

The GIWU consists of both hardware and software that provides an interface to various networks for data communications. Through the GIWU, users can alternate between speech and data during the same call. The GIWU hardware equipment is physically located at the MSC/VLR.

Network Areas

The GSM network is made up of geographic areas. Which include cells, location areas (LAs), MSC/VLR service areas, and public land mobile network (PLMN) areas. Cell is the area given radio coverage by one base transceiver station. The GSM network identifies each cell via the cell global identity (CGI) number assigned to each cell. The location area is a group of cells. It is the area in which the subscriber is paged. Each LA is served by one or more base station controllers, yet only by a single MSC. Each LA is assigned a location area identity (LAI) number. MSC/VLR service area represents the part of the GSM network that is covered by one MSC and which is reachable, as it is registered in the VLR of the MSC. The PLMN service area is an area served by one network operator.

(1.5) GSM Specifications

Specifications for different personal communication services (PCS) systems vary among the different PCS networks. Listed below is a description of the specifications and characteristics for GSM. [2]

(a) Frequency band: The frequency range specified for GSM is 1,850 to 1,990 MHz (mobile station to base station).

(b) Duplex Distance: The duplex distance is 80 MHz. Duplex distance is the distance between the Uplink and Downlink frequencies. A channel has two frequencies, 80 MHz apart.

(c) Channel Separation: The separation between adjacent carrier frequencies. In GSM, this is 200 kHz.

(d) Modulation: Modulation is the process of sending a signal by changing the characteristics of a carrier frequency. This is done in GSM via Gaussian minimum shift keying (GMSK).

(e) Transmission Rate: GSM is a digital system with an over-the-air bit rate of 270 kbps.

(f) Access Method: GSM utilizes the time division multiple access (TDMA) concept. TDMA is a technique in which several different calls may share the same carrier. Each call is assigned a particular time slot.

(g) Speech Coder: GSM uses linear predictive coding (LPC). The purpose of LPC is to reduce the bit rate. The LPC provides parameters for a filter that mimics the vocal tract. The signal passes through this filter, leaving behind a residual signal. Speech is encoded at 13 kbps.

GSM Subscriber Services

There are two basic types of services offered through GSM: telephony (also referred to as Tele services) and data (also referred to as bearer services). Telephony services are allows the mobile users to communicate with one another. Data services provide the capacity necessary to transmit appropriate data signals between two access points creating an interface to the network. In addition to normal telephony and emergency calling, the following subscriber services are supported by GSM [3]

Dual-Tone Multi Frequency (DTMF)

DTMF is a tone-signaling scheme often used for various control purposes via the telephone network, such as remote control of an answering machine.

Short Message Services (SMS)

A convenient facility of the GSM network is the short message service. A message consisting of a maximum of 160 alphanumeric characters can be sent to or from a mobile station. This service has a number of advantages. If the subscriber's mobile unit is powered off or has left the coverage area, the message is stored and offered back to the subscriber when the mobile is powered on or has reentered the coverage area of the network. This function ensures that the message will be received.

Cell Broadcast (CB)

A variation of the short message service is the cell broadcast facility. A message of a maximum of 93 characters can be broadcast to all mobile subscribers in a certain geographic area. Typical applications include traffic congestion warnings and reports on accidents.

Voice Mail (VM)

This service is actually an answering machine within the network, which is controlled by the subscriber. Calls can be forwarded to the subscriber's voice-mail box and the subscriber checks for messages via a personal security code.

Fax Mail (FM)

With this service, the subscriber can receive fax messages at any fax machine. The messages are stored in a service center from which the subscriber via a personal security code to the desired fax number can retrieve them.

Call Forwarding

This service gives the subscriber the ability to forward incoming calls to another number if the called mobile unit is not reachable, if it is busy, if there is no reply, or if call forwarding is allowed unconditionally.

Barring of outgoing calls

This service makes it possible for a mobile subscriber to prevent all outgoing calls.

Barring of incoming calls

This function allows the subscriber to prevent incoming calls. The following two conditions for incoming call barring exist: baring of all incoming calls and barring of incoming calls when roaming outside the home PLMN.

Advice of Charge (AoC)

The AoC service provides the mobile subscriber with an estimate of the call charges. There are two types of AoC information: one that provides the subscriber with an estimate of the bill and one that can be used for immediate charging purposes. AoC for data calls is provided on the basis of time measurements.

Call Hold

This service enables the subscriber to interrupt an ongoing call and then subsequently reestablish the call. The call hold service is only applicable to normal telephony.

Call Waiting

This service enables the mobile subscriber to be notified of an incoming call during a conversation. The subscriber can answer, reject, or ignore the incoming call. Call waiting is applicable to all GSM telecommunications services using a circuit-switched connection.

Multiparty Service

The multiparty service enables a mobile subscriber to establish a multiparty conversation—that is, a simultaneous conversation between three and six subscribers. This service is only applicable to normal telephony.

Calling line identification presentation/restriction

These services supply the called party with the integrated services digital network (ISDN). The restriction service enables the calling party to restrict the presentation. The restriction overrides the presentation.

Closed User Groups (CUGs)

CUGs are generally comparable to a PBX. They are a group of subscribers who are capable of only calling themselves and certain numbers.

Chapter 2

Cellular system design and its Minimization techniques in the design of the *LR* area

(2.1) Cellular system design Principles

During early development of the Cellular systems there are no systems existed and the most of the work is concentrated primarily with the characteristics of various idealized hex cell configurations for frequency reuse [24]. Classical descriptions of the system growth were in terms of the uniform cell patterns. In these experiments cells are subdivided at the growth points in the system evolution, often in the sets of full patterns, without detailed evaluation of the system needs and cost impacts on individual cells [24]. As time goes on adjustments were introduced into the system planning for variations in cell sizes, different user categories, and for the geographical conditions. Expansion and the subdivision appear in the individual cells rather than group of cells at once. The new cells are likely to be phrased in through overlay cells instead of whole new patterns appearing suddenly. These overlay cells were added in an exiting cell pattern in response to the user density concentration, which does not really justify the whole addition of new pattern. As per the change in the density concentration the frequency of allocation should change dynamically. The problem of steadily increasing the demand for the land mobile radio services is the introduction of Cellular zone systems. Although the reuse of the assigned radio channels in the spatial domain makes it possible to realize a more intensive use of the frequency spectrum, it also leads to potential co-channel interference. The problem of co-channel interference can be avoided by ensuring a minimum distance between *BS's* using the same radio channel frequencies. The level of co-channel interference should be low enough to be compatible with the transmission quality of landline Networks. The fundamental parameters for designing the Cellular land mobile systems are Cellular layout, mobile radio environment, and the transmission quality.

In the Cellular layout cell configuration *BS* is located at the centre of the each cell. This hex structure is suitable for the service area covered by the omnidirectional antenna. The maximum distance from the centre of the cell to its boundary is *R*. The distance between the *BS* and the closest interference stations is $D=\sqrt{3C_h}\,R$, where C_h is the number of channel sets in a cluster [25]. A unit cluster consists of six *BS*'s which are set at equal distances from the *BS's* of interest

In the mobile radio environment the propagation in the VHF/UHF bands are characterized by path loss, log normal shadowing, and Rayleigh fading [26]. Path loss is characterized by index of propagation law, the local mean signal strength and is log-normally distributed. Transmission quality is mainly governed by protection ratio. Its specific value is measured for various modulation methods, for instance, with the function of signal plus noise plus distortion to noise plus distortion [26]. The protection ratio adopts the threshold value of signal to interference power ratio to maintain the required quality level.

(2.1) Location Tracking Strategies:

Higher user density and high mobility is the characterization of the *PCS*. The large number of registrations and handoffs is the cause of more load on radio link. *PCS* provides voice and data communication services to the stationary and non-stationary mobile Subscribers with out the space restrictions within the geographic area. *PCS* introduces three capabilities to communicate with a person at any time, at any place [26].

(1) Terminal mobility provided wireless access
(2) Personal mobility based on personal members
(3) Service mobility through management of user service profiles

In *PCS* mobility management plays a very important role. Location Tracking is one of the important things in the mobility management. Current Cellular systems uses geographic based registration in which a registration occurs when a user crosses the boundary formed by a group of cells, called a location area. Location area size has considerable impact on the radio bandwidth. Since in *PCS*, *MS* mobility is controlled through location registration and *updating*. Number of strategies are proposed to find out the *MS* in such a fashion to reduce the signaling overhead. Different approaches for location *updating* may result in improved performance. If the position of a user known in advance, then no explicit registration is necessary. Thus the optimum location area is one that minimizes the *paging* cost. By maintaining the past history of the movements of *MS*, the frequency of locating the users can be reduced [20].

In comparison between Cellular mobile communications and PCN (Personal Communication Networks), the only differences are due to radio link, interference of signals, cell size, mobility and call pattern of *MS* [26]. A *PCN* consists of two levels. One is stationary level and the other one is mobile level. At the stationary level, *MSC* plays very important role. Its purpose is setting the connection for the mobile user, and in the allocation of channels. The *MSC* interconnects with another *MSC* and public fixed Networks, in which *MSC* connected to mobile station with other mobile station using *BS* in between them. *MSC* is connected *STP* (Signal Transfer Point) which in turn connected to *SCP* (Signal Control Point) such as *HLR* (Home Location Register) and *VLR* (Visitor Location Register). Which are used for database transactions and for call control mechanisms. *HLR* maintains the mobility characteristics of the mobile user and also maintain the features of group of users. The group of users is divided into three categories based on these three possible classes [21].

(1) Deterministic users: In this case the system does know the position of the *MS*, as the *MS* does not need to register.

(2) Quasi-deterministic users: In this case the *MS* move very slightly from day to day. They behave in such a fashion that we can found out with maximum probability.

(3) Random users: For the Random Users *HLR* can not detect them based on the past knowledge it has, profile based location strategy is not suitable for this type of users. For this case the best strategy is to page the incoming calls where the *MS* is last contacted with the *BS*.

HLR maintains a link with *VLR* so that an in coming call of the *MS* to be routed successfully. As the *MS* moves from one *LR* area to another *LR* area or with in the *LR* area the contents of the *VLR* changes dynamically. The functions of *VLR* are checking the location *updating* of *MS*, allocation of Temporary mobile Station Identity (TMSI) for location confidentiality and storage of mobile Station Roaming Number [26]. In mobile Level the mobile users are moving fastly or by walk. They communicate with the *BS* via by wireless links. Each *BS* covering the fraction of up to ten's of kilometers. An *MS* has radio communication link with each of the *BS*. There is no restriction on the movement of *MS* with in the *BS* area. Calls are routed successfully regardless of the positions of the *MS* who made the call and the *MS* who received the call. In *PCS* the mobile user mobility is controlled based on the location *updating* and location registration strategies. Whenever the *MS* moves out of the vicinity of the *LR* area then the location *updating* holds as well the *VLR* is also updated based on the movements of the *MS*. Location registration is based on location area, it provides the compromise between the location *updating* and *paging* procedure. Various numbers of strategies are proposed for the location tracking to minimize the overhead on radio link produced by *LU* and *paging*.

Location tracking Strategies

(a) Awerbuch and Paleg [23] provide a formal model for tracking mobile users. This strategy is based on hierarchy of group of regions (or) location areas, An incoming call is sent to the user based on previous location of the user, and the areas where the user is moving. Since the mobile user can move any of the cells that is adjacent to the previous cell. For tracking the mobile user the near by cells are updated and are recognized as reporting cells. To provide access to the mobile users in the remote cells a forward pointer is used in the previous cell so that directly the position of the user is maintained.

(b) Second strategy is based on hierarchical architecture based on the Metropolitan Area Network (MAN) proposed by L.J.Ng [24]. In this paper they considers three levels of databases and they are access MAN, backbone MAN and metropolitan MAN. Metropolitan MAN maintains Database of all the users about their mobility characteristics, so that any reference with the *MS* is maintained by it only. All of the Metropolitan MAN's are interconnected to the central office. Home access MAN maintains the database of every user. So that whenever the user is out side the home the Home access MAN sets a pointer where the user usually roams. The directory database maintains information of every mobile user about the Home access MAN. Hence this database is very large and the probability of finding the user is absolute by this procedure.

(c) Imilinski and Badrinath [25] discuss an issue of database queries for tracking mobile users by partitioning the user's location knowledge across the Network. Even though this approach has two drawbacks. The partition of user mobility patterns to maintain a certain degree of knowledge about a user's whereabouts is the optimal partitioning problem that minimizes the expected cost of querying and *updating*. The optimal partitioning problem makes this approach difficult to implement. Query Processing is another disadvantage in the presence of imprecise knowledge about the user locations.

(d) Madhow [26] considers a distance-based strategy. In Cellular environment an incoming call is paged at very high rate in the *LR* area. So at the time of *paging* the system is not in the steady state. In this situation when the *MS* moves the distance which is more than the threshold then the location *updating* holds. Paging using the same *BS* is not possible when the *MS* moves out of the *BS* area. This distance based strategy considers the evaluation of the system between two successive pagings. Hence for the optimal value this strategy uses the dynamic programming approach.

(e) Tabbane [20] introduces an intelligent method of locating users called an alternative strategy (AS). This proposal based on the observation that the mobility behavior of a majority of users can be predicted. This strategy can reduce signaling messages involved in mobility management procedures, leading to savings in system resources. This approach reinforces the information capabilities of the system, and provides tools for prediction by integrating more information about the external world. The main advantage of this scheme is to save location updates by storing user's mobility information in profiles. Draw backs are possibility of increased *paging* delays (When the user must page a user in different locations in a sequential manner), increased memory requirements, and profile *updating* costs for users, which do not have long-term periodic mobility patterns.

(f) This is the Novel Tracking strategy proposed by A.Hac, X. Zhou in [22] propose a new scheme to partition and track mobile users and its implementation based on Cellular architectures. In this architecture *MS* transmits an update message only at specific cells called the reporting cells, while the search for a *MS* is done only in those cells where the last reported. In the algorithm proposed by them they use a cost analysis model to demonstrate the feasibility of *updating* cost and *paging* cost to reduce the resources in using the wireless channels. They also simulated performance comparison of schemes such as always update, always search and the model as discussed above.

(2.3) Minimization Techniques

A mobile unit must be paged over a set of possible locations (location area) in order to establish a connection between the calling party and the mobile. Since *LU* and *paging* requires the use of radio resources beyond those needed to carrying traffic, it is necessarily required to provide the minimum amount of *LU*, *paging* bandwidth necessary to support some given level of service [21]. In the Cellular Networks locating an *MS* in time has become the important factor with the available wireless resources. An efficient use of limited wireless resources in emerging *PCS* requires much smaller cells than those used in the conventional Cellular Networks. As the cell sizes are changing tracking of *MS* becoming a challenging task. In order to ensure reliable communication, a *MS* has to send/receive signaling messages from the *BS* depending on the system design, signaling messages for various purposes such as frame synchronization, *BS* identification, mobility management, and hand off decision making etc. Over the last few years radio spectrum had become the scarce commodity because of increase in the number of *MS*'s and the available resources [22]. This calls for a reduction in the signaling load between the *BS* and *MS* to make more bandwidth available for both voice and data traffic. One way to reduce the signaling overhead is to employ Cellular Networks with more intelligent *paging* and *LU* strategies. The minimization techniques that are useful in the minimization of this signaling overhead is given below.

Minimization Strategies:

(a) This strategy was proposed by A. Yener and C. Rose [22]. In this strategy during *paging* process the *MS*'s are allowed to move. It is shown that the strategy which minimizes the average number of *paging* events or the average *paging* delay or the combination of these two must search the conditionally most likely locations after each polling failure [21]. Therefore the problem of finding the best strategy is reduced to finding how many locations to include to each polling group. The problem of finding the optimal polling group is not possible to standard methods such as dynamic programming. For that they considers heuristic or approximate principles. They observed that as the time interval between polling events increases, the number of locations searched earlier in the *paging* process must increase until it becomes optimal to poll all locations. For blanket polling strategy this effect occurs only at extreme levels of mobility where a failed polling event provides little information about unit location just prior to next scheduled polling event. The effect of increasing the importance of delay reduction had the expected effect of lowering delay at the expense of increased *paging* cost. However the polling strategy lowered the *paging* strategy as compared to classical strategy but with the little increase in the average delay. Thus it may often be more efficient to sacrifice a small amount of delay performance and thereby a substantial reduction of *paging* cost.

(b) This intelligent *paging* strategy developed by G.L.Lyberopoulos, J.G.Markoulidakis, D.V.Polymeros, D.F.Tsirkas, and E.D.Sykas [23]. In this strategy at the instance of call terminating *paging* is performed with in the portion of the *LR* area. On no *paging* response the *paging* is performed in the complementary portion of the *LR* area. The effectiveness of the strategy is directly related to the capability of the Network to accurately predict the called *MS* location. This intelligent *paging* reduces the *paging* signaling load reduction of the order of 70% or higher compared to techniques applied to GSM. This allows for the definition of larger LA's and therefore may lead to the minimization of the *LU paging* load. With this strategy significant increase in the number of *MS* does not effect resulting signaling load. The only disadvantage with this technique is additional database is required for the storage purposes. The diagrammatic representation of operations upon arrival of incoming call to the *MS* is shown in figure (5).

(c) R. Rezaiifar and A.M.Makowski [24] has developed a strategy called Novell-*paging* strategy based on theory of optimal search with discrete efforts. When compared to conventional *paging* methods it minimizes the time that is required to find out the *MS* and it also minimizes the average number of times that a BS has to page in a *LR* area. This strategy uses the combination of optimal search and stochastic approximate methods. This algorithm has two advantages over conventional methods, one is it reduces the signaling load and significantly expedites the *paging* process, and the second one is this method is computationally very simple. And does not add to the complexity of the system. By simulation results they also shown that the Sequential *paging* algorithm proposed by them performs well under both heavy and light loads, and is more advantageous over the conventional sequential *paging* algorithms.

(d) This is the profile-based technique used to reduce the cost of *LU* developed by G.P.Pollini and Chin-Lin I [25]. This strategy is based on every day schedules or movements of users. Which can exploited the current location of the user. The system maintains the list of *LR* areas orderly in a linked fashion as per the priority basis in which the *MS* usually roams. When a call arrives for the user it paged sequentially in that order until the *MS* is found. There are four factors, which determines the effectiveness as given by these authors. They are

(i) The number of location areas in the list
(ii) The average number of location areas that the system must page before finding the user *E[k]*
(iii) The likelihood that the user is in any location with in the list
(iv) The cost of maintaining the list with in the Network.

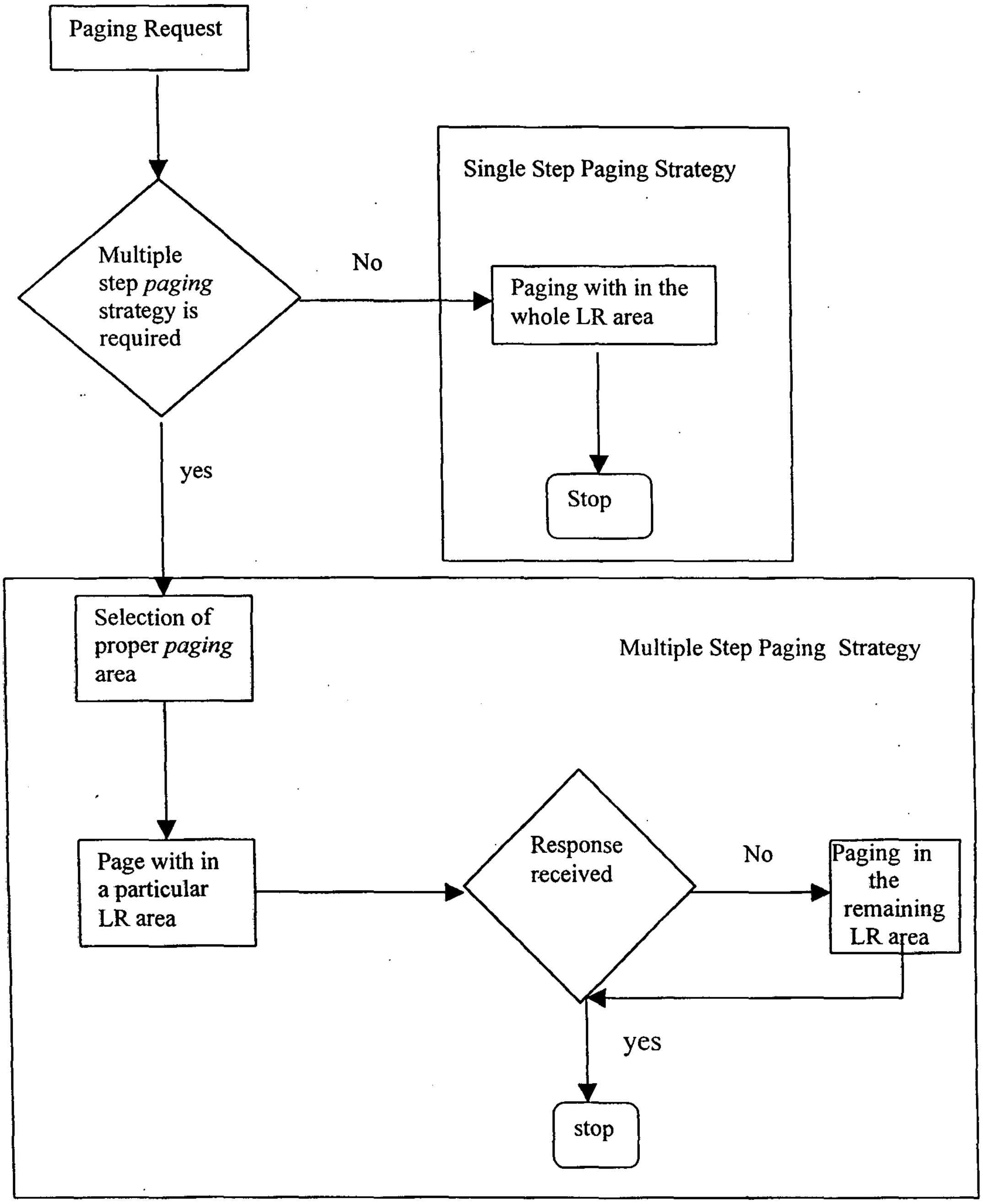


Figure.5 Network Operations upon arrival of a *paging* request

Using these four quantities they derived the following

(i) This scheme is more advantageous for mobile users.

(ii) The call setup delay increases with the number of cells with in the *LR* area, this number of cells are odd for good result.

(iii) The total radio link traffic is reduced when *k* is less than some threshold. This threshold value depend on *E[k]*

(e) S.J.Kim and C.Y.Lee [26] considered the *0-1* integer-programming model to determine the most appropriate dynamic *LR* area. This model is based on the MS mobility characteristics, incoming call rates, and the structure of the *LR* area. In this model they decomposed the *0-1* integer-programming problem into a number of decision problems each of which decides whether the cell is included in the *LR* area is not. A cell is added to *LR* area only if the *updating* cost is greater than the *paging* cost. This dynamic *LU* procedure performs well for the square and irregular *LR* areas.

(f) Y.B.Lin, W.N.Tsai [20] proposed an algorithm called *pointer forwarding*, which is useful in minimizing the *LU* cost. The main theme in the forwarding is that if the user's made frequent *LU's*, but receive calls infrequently then it is possible to avoid the registrations at the *HLR* database by setting up a forward pointer from the previous *VLR.* Calls to *MS* will first query to user's *HLR* to determine the first *VLR*, which the user was registered at, and then follow a chain of forwarding pointers to the current *VLR.* To reduce the *LU* cost the *PCS* service providers may distribute *HLR* databases at the in the Network. In this paper they proposed a new scheme called pointer forwarding with distributed *HLR*.

Chapter 3

Mobility model and characterization of mobility patterns of *MS*

(3.1) Mobility Model

PCS is an extension and integration of future wireless communication network facilities, ultimately allowing the general public to make calls to reach anyone, anywhere, and at any time. It is very important to analyze mobility patterns and its effects on *MS* in order to implement *PCS* [29]. In mobile communications, mobility modeling is involved in several aspects related to signaling and traffic analysis. In third generation systems, the influence of mobility on the network performance (e.g., handover rate) will be strengthened, mainly due to the huge number of mobile users in conjunction with the small cell size. The accuracy of mobility models becomes essential for the evaluation of system design alternatives and network implementation cost issues. Mobility model plays a very important role in viewing different issues involved in a cellular system such as hand over, offered traffic, dimensioning of signaling network, user location updating, registration, paging, multi layer network management, and like the more [27]. In a general case it also involves the direction in which the mobile is moving. In proposed model the direction in which the mobile is moving is deterministic and the path the *MS* follows in moving from starting cell to any other cell is linear and predictable one. The Mobility Model Proposed in this paper considers two methods. One is based on fluid model of mobility where each of the *MS* movement is uniformly distributed in the range of [0,2Π] which we are going to discuss in this chapter and the other one is based on greedy approach, In which directional preference is taken into consideration which is explained in the next chapter. In the Fluid Model of Mobility the optimum position of the *MS* would be at the center of the *LR* area. In comparison to these two approaches, Greedy Method shows the best performance result in the design of the *LR* area. Since this method incorporates the directionality aspects. In the Fluid Model the *MS* moves are based on the probabilities of each direction rather than the direction in which the *MS* is already moving.

The last few years experienced a tremendous growth in the field of cellular communications. This is the cause of designing the user specific *LR* areas, which depend on the *LU* and incoming call rate in the current geographic position of the system. But the design of the *LR* area specific to a particular user is not possible. But for the current systems the *LR* area is designed per group of people with similar incoming call rates and mobility patterns. The movement of the *MS* is based on the orientation of the *LR* area and the time of the day i.e., *MS* is moving towards office during morning time and in oppositely during the evening time. For the mobility model we are considering the model in the two-dimensional grid architecture as shown in figure (6).

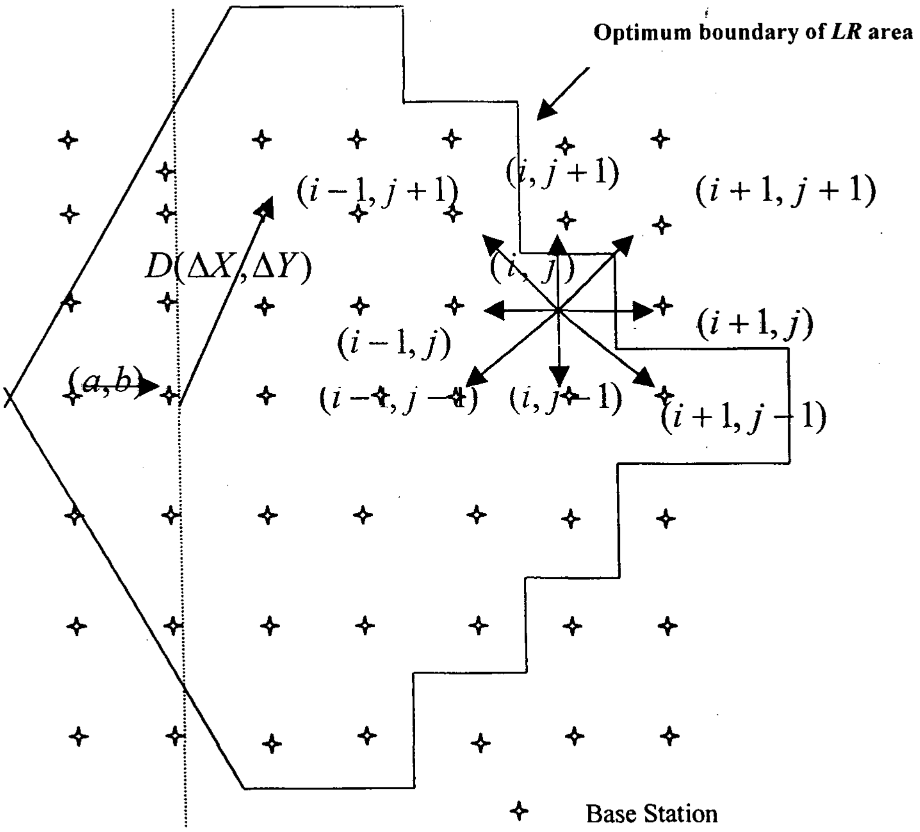


Figure 6: Example of modified distance based updates

In the design of the *LR* area we are not concerned about each and every user mobility characteristics i.e., speed and the direction in which the *MS* is moving. Rather we take average update rate by assuming that different times *MS*'s spend in the respective cells. These times are independent identically distributed random variables. Average update rate is the rate of traversing one cell divided by the number of cells traversed in the *LR* area. This is given by

$$\mu_k = \mu_1 / N_k \tag{3}$$

where μ_k is the average update rate, μ_1 is the rate of traversing in one cell, and N_k is the expected number of cells traversed in the *LR* area containing *k* cells before exiting the *LR* area. In order to calculate the number of cells traversed in our mobility model the *LR* area considered is shown below. In this *LR* area any cell can be reached from the starting cell having coordinates (a,b) by using the shortest distance model which is explained in the next section. Let $\Pr(v(i,j)/n)$ denotes the probability of visiting any cell (i,j) on the boundary of an *LR* area after n movements in the *LR* area, and let $\Pr(e(i,j)/n)$ denotes that (i,j) is the last cell before exiting the *LR* area after n movements in the *LR* area after starting from the *LU* cell with coordinates (a,b). There is a relation between $\Pr(v(i,j)/n)$ and $\Pr(e(i,j)/n)$ as is evident from figure (6), it is following the equation given by Abutaleb and li [3]

$$\Pr(e(i,j)/n) = \Pr(v(i,j)/n)\ p_1 + \Pr(v(i,j)/n)\ p_2 + \Pr(v(i,j)/n)\ p_3 \tag{4}$$

where $P_i, i = 1,\ldots,8$ is the probabilities of moving to *(i,j+1), (i+1,j+1), (i+1,j), (i+1,j-1), (i,j-1), (i-1,j-1), (i-1,j), (i+1,j-1).*In our Mobility analysis we would like to concentrate more on Vehicular *MS*'s rather than pedestrian users because they are highly mobile and generate high traffic.

(3.2) Shortest Distance Model:

Using the Mobility Model discussed above we are developing the shortest distance model for various movements of the *MS*. For this model to develop we are considering the grid architecture as shown in figure (6). Starting from the LU cell with coordinates (a,b), *MS* follows the Shortest Path, in which the number of cells the *MS* traverse is less than the path length between source and destination. At each intersection *MS* moves to next cell satisfying the probabilities of each direction and the shortest distance assumption. To demonstrate the movements of *MS* we are defining the following parameters S denotes moving straight ahead at intersection, L denotes moving Left at the intersection, R denotes moving Right at the intersection, $D1$ denotes moving towards the left diagonal at intersection, $D2$ denotes moving towards Right diagonal at intersection. Let ϕ denotes the random variable that denotes the last turn performed by the *MS* in the *LR* area, and for our model it is given by $\phi = \{L, D1, D2, R\}$

Unconditional probabilities of moving to left, left diagonal, straight, right diagonal and right directions is given by $\Pr(L) = P_L$, $\Pr(D1) = P_{D1}$, $\Pr(S) = P_S$, $\Pr(D2) = P_{D2}$, $\Pr(R) = P_R$ such that $P_L + P_{D1} + P_S + P_{D2} + P_R = 1$. Now we are calculating the probabilities of moving to various directions. If the last turn performed by the *MS* with in the *LR* area is L, then the probability of moving to other directions is given by

$$\Pr\{L/\phi = L\} = 0 \qquad \Pr\{R/\phi = L\} = 0$$
$$\Pr\{D1/\phi = L\} = 0 \qquad \Pr\{D2/\phi = L\} = 0 \tag{5}$$

If the last turn performed by the *MS* with in the *LR* area is R, then the probability of moving to other directions is given by

$$\Pr\{L/\phi = R\} = 0 \qquad \Pr\{R/\phi = R\} = 0$$
$$\Pr\{D1/\phi = R\} = 0 \qquad \Pr\{D2/\phi = R\} = 0 \tag{6}$$

If the last turn performed by the *MS* with in the *LR* area is $D1$, then probability of moving to other directions is given by

$$\Pr\{L/\phi = D1\} = 0$$

$$\Pr\{R/\phi = D1\} = 0$$

$$\Pr\{D1/\phi = D1\} = {}^{P\,D1}\!\Big/\!(P_{D1} + P_{D2} + P_S)$$

$$\Pr\{D2/\phi = D1\} = {}^{P\,D2}\!\Big/\!(P_{D1} + P_{D2} + P_S) \tag{7}$$

If the last turn performed by the *MS* with in the *LR* area is $D2$, then probability of moving to directions given by

$$\Pr\{L/\phi = D2\} = 0$$

$$\Pr\{R/\phi = D2\} = 0$$

$$\Pr\{D1/\phi = D2\} = {}^{P\,D1}\!\Big/\!(P_{D1} + P_{D2} + P_S)$$

$$\Pr\{D2/\phi = D2\} = {}^{P\,D2}\!\Big/\!(P_{D1} + P_{D2} + P_S) \tag{8}$$

In this model we have considered only the vehicular subscribers, the traffic flows out of and into a cell is used to measure the $P_L, P_{D1}, P_S, P_{D2}, P_R$. Using these probabilities we are going to calculate probabilities of moving in various directions, which in turn are useful for the calculation of $\Pr(v(i,j)/n)$ and N_K, required in the optimization problem which we are going to discuss in the next chapter.

(3.3) Shortest Distance Model in developing various parameters related to *LR* area design

In this section we are obtain $\Pr(v(i,j)/n)$ and N_K by using the equations (3) to (8) which we have derived in the previous section. In the derivation of $\Pr(v(i,j)/n)$ we use an algorithm which follows recursively. This algorithm calculates the probability of visiting each cell in all directions. We derive the following equation

$$\begin{aligned}\forall(i,j)\Pr(v(i,j)) = E(i,j) + S(i,j) + N(i,j) + W(i,j) + \\ SE(i,j) + SW(i,j) + NW(i,j) + NE(i,j)\end{aligned} \tag{9}$$

where $E(i,j), S(i,j), N(i,j), W(i,j), SE(i,j), SW(i,j), NW(i,j), NE(i,j)$ denote respectively the probability of visiting the cell (i,j) from East, South, North, West, South-East, South-West, North-West and North-East directions respectively. Let us assume (a,b) the coordinates of the starting cell, such that a cell (i,j) in the *LR* area can reached after traversing these number of cells

$$\begin{aligned} &|i-a|+|i-b|+|j-i| \quad \text{if} \quad j>i \\ &|j-a|+|j-b|+|j-i| \quad \text{if} \quad i>j \end{aligned} \tag{10}$$

Let *x* is the binary $m \times m$ square matrix denotes the cell assignments in the *LR* area for each *MS* or the shape of the *LR* area. The value of $x_{i,j}$ is assigned if the cell (i,j) has already been visited. If $x_{i,j}$ is zero this means cell (i,j) is not assigned i.e., the *MS* has not yet visited that cell. Using *x* we calculate N_K, the average number of cells traversed in the *LR* area before exiting. Following is the recursive iterative algorithm, which is useful in deriving $\Pr(v(i,j)/n)$ and N_K further this algorithm derives the equation (7).

Algorithm

This recursive iterative algorithm considers the shortest paths in calculating $\Pr(v(i,j)/n)$. This is the thirteen-step algorithm which takes number of cases into consideration.

Step1: Initialize all the probabilities to zero. i.e., probability of visiting all the cells from all directions is zero, $E(i,j)=0$, $S(i,j)=0$, $N(i,j)=0$, $W(i,j)=0$,

$SE(i,j)=0$, $SW(i,j)=0$, $NW(i,j)=0$, $NE(i,j)=0$, where (i,j) is for all the cells of *X*.

Step 2: Since *LU* cell with coordinates (a,b) is the entry for the *MS*. *MS* enters this cell from the West direction, then the cell assignments becomes, $E(a,b)=0$, $S(a,b)=0$, $N(a,b)=0$, $W(a,b)=1$, $SE(a,b)=0$, $SW(a,b)=0$, $NW(a,b)=0$, $NE(a,b)=0$.

Step 3: $n=1$, index pointer which is useful for counting the fixed number of cells.

Step 4: This step calculates the probability of visiting all the cells with the same y-coordinate of the LU cell. In the grid architecture shown in figure (6) *MS* moves from West direction of cells. i.e., $(a+n,b)$ as shown in figure 7.

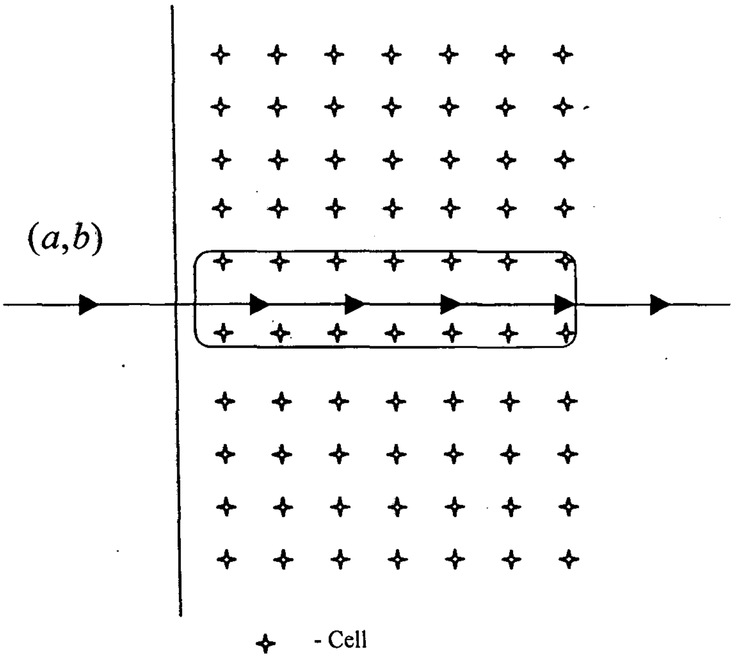


Figure 7. *MS* movements only through the West direction of cell (a,b)

By using the above figure the equation for $W(a+n,b)$ can be written recursively as

$$W(a+n,b)=W(a+n-1,b)P_{S}x_{a+n-1,b} \tag{11}$$

step 5: This step calculates the probability of visiting all the cells with the same X-coordnate as that of the *LU* cell. Shortest distances starts from cell (a,b) to south direction and north direction respectively. The diagrammatic representation for it is shown in figure 8

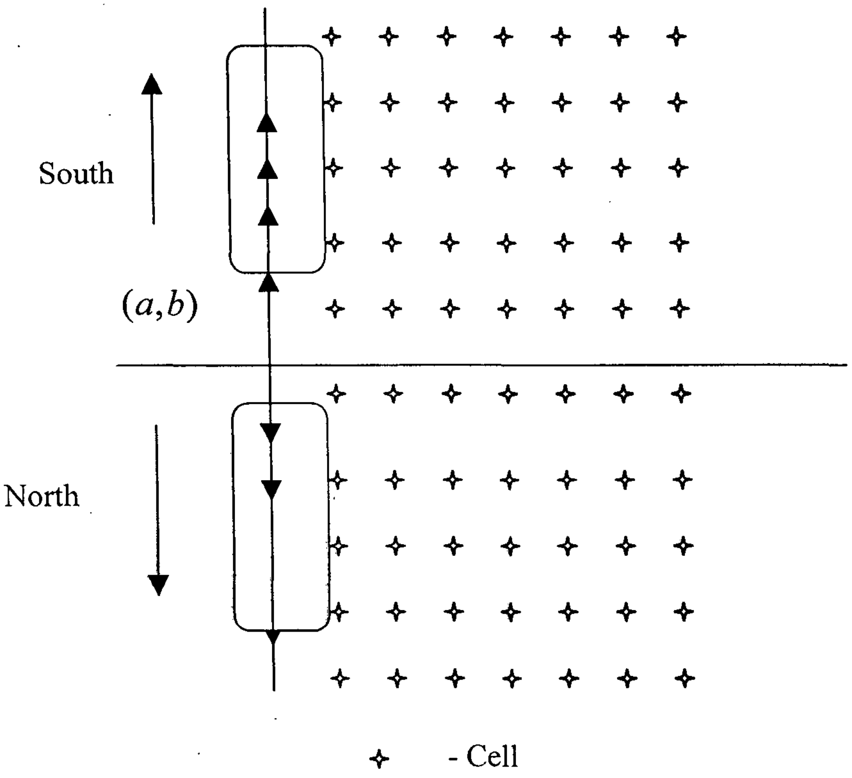


figure 8. *MS* movements through west and south directions

From the above figure, the equation for $S(a,b+n)$, $N(a,b-n)$ can be written recursively as shown below

$$S(a,b+n) = (D1(a-1,b+n-1)P_{D1} + S(a,b+n-1)(\frac{P_S}{P_S + P_{D2}}) \qquad (12)$$

$$N(a,b-n) = (D2(a+1,b-n+1)P_{D2} + N(a,b-n+1)(\frac{P_S}{P_S + P_{D1}}) \qquad (13)$$

Step 6: $n = n+1$ goto step 4 until the same X and Y coordinates as the LU cell have been calculated.

Step 7: n=2

From this step we calculate the probability of visiting all the remaining cells that are reachable from the LU cell using the shortest distance paths. Since the paths to be followed are the shortest paths such that the shortest path condition should be satisfied. The condition is

$$|i-a|+|i-b|+|i-j|=n \quad \text{if } i<j$$
$$|j-a|+|j-b|+|j-i|=n \quad \text{if } i>j \tag{13 a}$$

<u>Step 8</u> : If $i > a$ and $j \neq b$ and if $j > b+1$ the diagrammatic representation of it is shown in figure 9

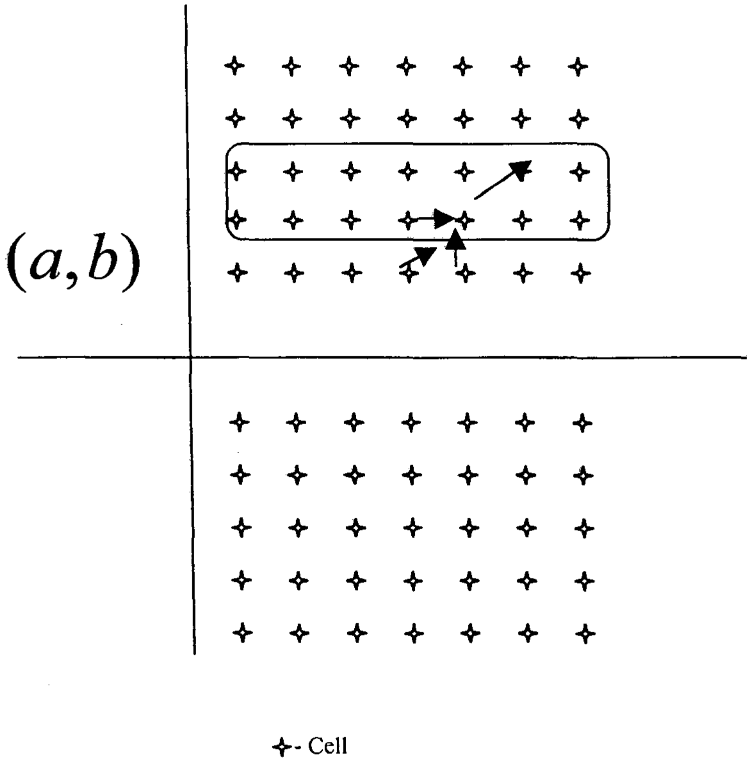


figure 9: *MS* movements if $j > b+1$

The recursive equations satisfying the above diagram are

$$W(i,j) = (W(i-1,j)(P_S / P_S + P_{D1}) + D1(i-1,j)(P_{D2} / P_{D1} + P_s + P_{D2}) \tag{14}$$

$$D1(i,j) = (W(i-1,j-1)(\frac{P_{D1}}{P_S + P_{D1}}) + D1(i-1,j-1)(\frac{P_s}{P_{D1} + P_s + P_{D2}}) + S(i-1,j-1)(\frac{P_{D2}}{P_{D1} + P_s + P_{D2}})) \tag{15}$$

$$S(i,j) = S(i,j-1)(\frac{P_S}{P_s + P_{D2}}) + D1(i,j-1)(\frac{P_{D1}}{P_{D1} + P_S + P_{D2}}) \tag{16}$$

step 9: If $i > a$ and $j \neq b$ and if $j < b-1$ the diagrammatic representation of it is shown in figure 10. The recursive equations satisfying the diagram are

$$W(i,j) = (W(i-1,j)(\frac{P_S}{P_S + P_{D2}}) + D1(i-1,j)(\frac{P_{D1}}{P_{D1} + P_s + P_{D2}}) \tag{17}$$

$$D1(i,j) = (W(i-1,j+1)(\frac{P_{D2}}{P_S + P_{D1}}) + D1(i-1,j+1)(\frac{P_s}{P_{D1} + P_s + P_{D2}}) + N(i-1,j+1)(\frac{P_{D1}}{P_{D1} + P_s + P_{D2}})) \tag{18}$$

$$N(i,j) = N(i,j+1)(\frac{P_S}{P_s + P_{D1}}) + D2(i,j+1)(\frac{P_{D2}}{P_{D1} + P_S + P_{D2}}) \tag{19}$$

step10: If $i > a$ and $j \neq b$ and if $j = b+1$ the diagrammatic representation is shown in figure 11.The recursive equations satisfying the diagram are

$$W(i,j) = (W(i-1,j)(\frac{P_S}{P_S + P_{D1}}) + D1(i-1,j)(\frac{P_{D2}}{P_{D1} + P_s + P_{D2}}) \tag{20}$$

$$D1(i,j) = W(i-1,j-1)(\frac{P_{D1}}{P_S + P_{D1}}) \tag{21}$$

step11: if $i > a$ and $j \neq b$ and if $j = b+1$ the diagrammatic representation is shown in figure 12.The recursive equations satisfying the diagram are

$$W(i,j) = (W(i-1,j)(\frac{P_S}{P_S + P_{D2}}) + D1(i-1,j)(\frac{P_{D1}}{P_{D1} + P_s + P_{D2}}) \tag{22}$$

$$D2(i,j) = W(i-1,j+1)(\frac{P_{D2}}{P_S + P_{D2}}) \tag{23}$$

step 12: $n = n+1$. Goto step 8 until all the cells that are reachable from the LU cell has been calculated

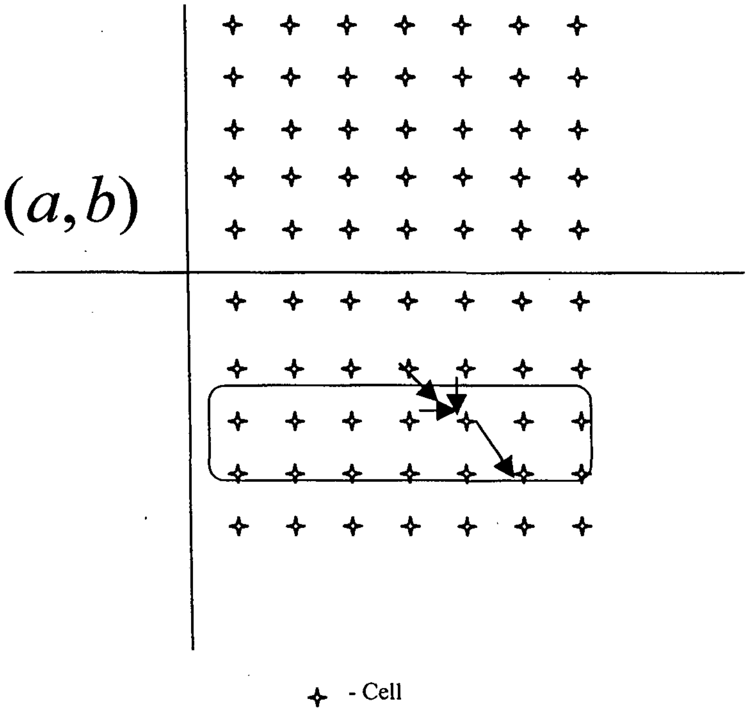


figure 10: *MS* movements if $j < b - 1$

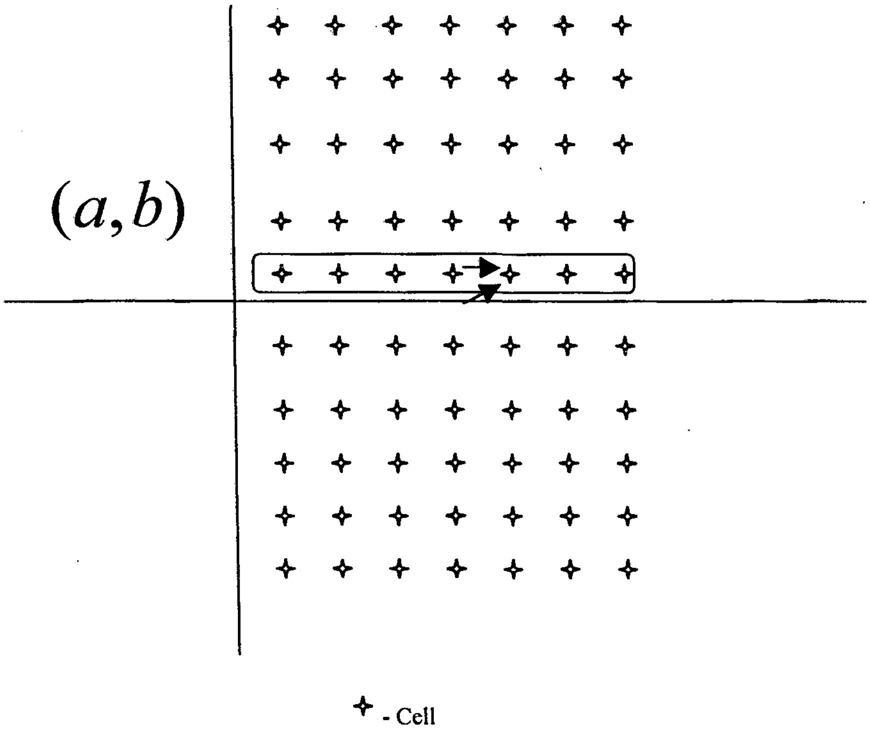


figure 11: *MS* movements if $j = b + 1$

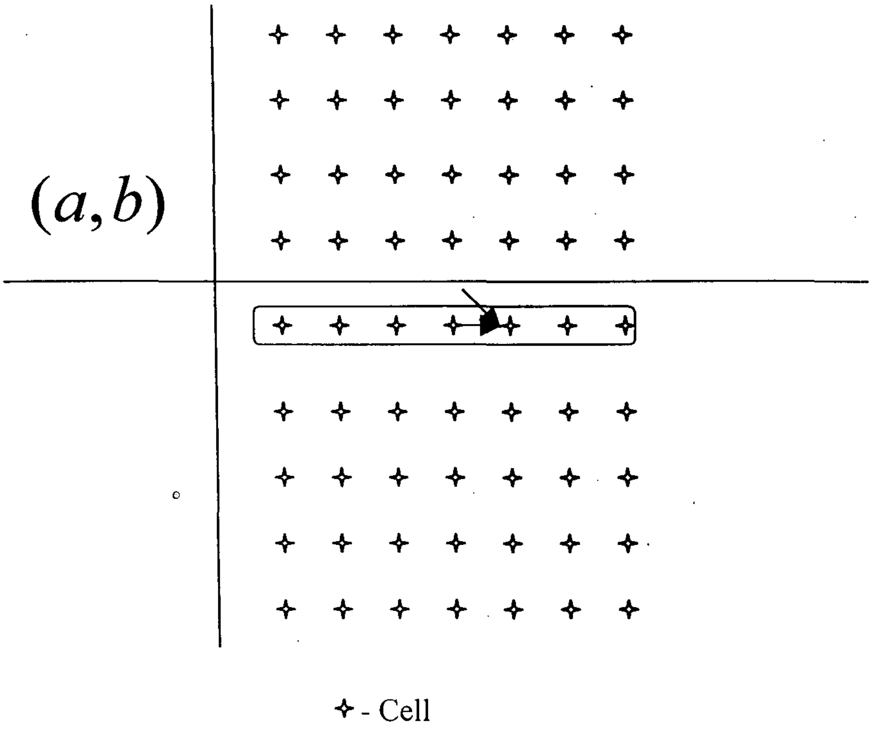


figure 12: *MS* movements if $j = b - 1$

Step 12: By using all of the above steps we can derive

$$\begin{aligned}\Pr(v(i,j)) &= E(i,j) + S(i,j) + N(i,j) + W(i,j) + \\ &SE(i,j) + SW(i,j) + NW(i,j) + NE(i,j) \qquad \forall(i,j)\end{aligned} \tag{24}$$

Derivation of N_K: The purpose of calculating all the parameters up to now is to design the *LR* area optimally. In the optimization problem calculation of N_K is the most important one because it calculates the number of cells traversed by *MS* in a *LR* area. For this calculation as well we are considering the figure (6). In this shortest distance model any cell on the boundary can be reached after traversing the number of cells as given in (13a).

$|i-a| + |i-b| + |i-j| = n \quad \text{if } i < j$

$|j-a| + |j-b| + |j-i| = n \quad \text{if } i > j \qquad$ (13 a)

where (i,j) is the cell that is on the boundary of the *LR* area, and (a,b) is the starting cell coordinates. The probability that cell (i,j) is the last cell *MS* visits before exiting the *LR* area is sum of the probabilities that the cell (i,j) is visited from the south direction $(i,j+1)$ the cell (i,j) visited from the south-west direction

$(i+1, j+1)$ or the cell (i, j) visited from the west direction $(i+1, j)$. Then for any (i, j),

$$\Pr(e(i,j)) = S(i,j+1) + SW(i+1,j+1) + W(i+1,j) \qquad (25)$$

It can also be written as $\Pr(e(i,j)) = E(i-1,j)\,\bar{x}_{i-1,j} + S(i,j+1)\,\bar{x}_{i,j+1} + N(i,j-1)\,\bar{x}_{i,j-1} + W(i+1,j)\,\bar{x}_{i-1,j} + SE(i-1,j+1)\,\bar{x}_{i-1,j+1} + SW(i+1,j+1)\,\bar{x}_{i+1,j+1} + NW(i+1,j-1)\,\bar{x}_{i+1,j-1} + NE(i-1,j-1)\,\bar{x}_{i-1,j-1}$, (26)

where $\bar{x}_{i,j} = 0$ if $x_{i,j} = 1$ else $\bar{x}_{i,j} = 1$ if $x_{i,j} = 0$

For any cell (i, j) it can be written as $\Pr(e(i,j)) = x_{i,j}\,(E(i-1,j)\,\bar{x}_{i-1,j} + S(i,j+1)\,\bar{x}_{i,j+1} + N(i,j-1)\,\bar{x}_{i,j-1} + W(i+1,j)\,\bar{x}_{i-1,j} + SE(i-1,j+1)\,\bar{x}_{i-1,j+1} + SW(i+1,j+1)\,\bar{x}_{i+1,j+1} + NW(i+1,j-1)\,\bar{x}_{i+1,j-1} + NE(i-1,j-1)\,\bar{x}_{i-1,j-1})$. (27)

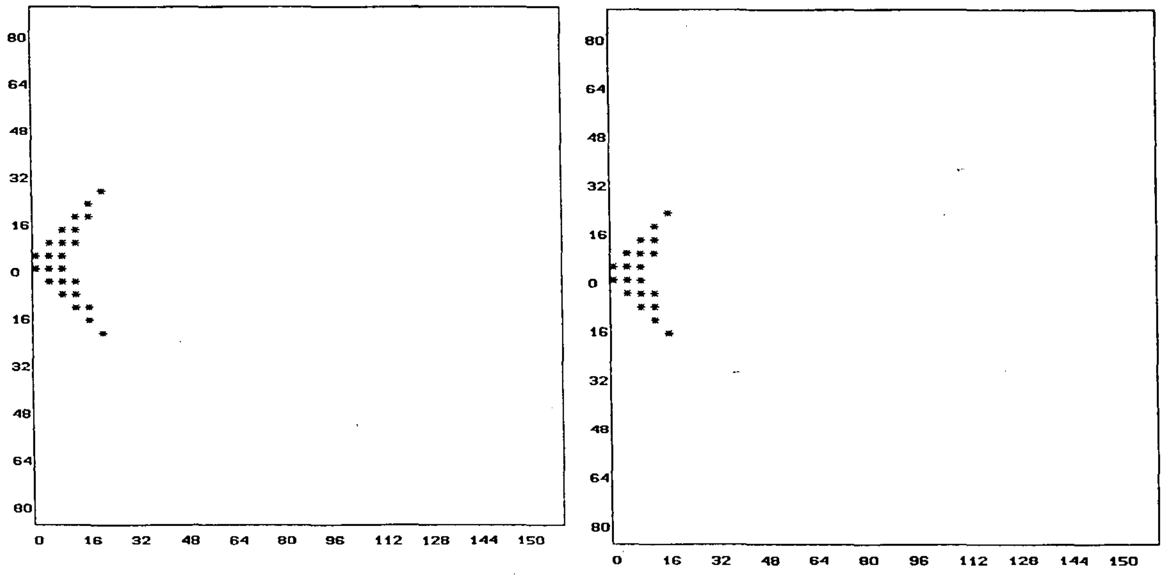
Based on that we can write $N_K = \sum_{(i,j)} dist \Pr(e(i,j))$ (28)

where $dist$ is $|i-a| + |i-b| + |i-j| = n$ if $i < j$

$|j-a| + |j-b| + |j-i| = n$ if $i > j$

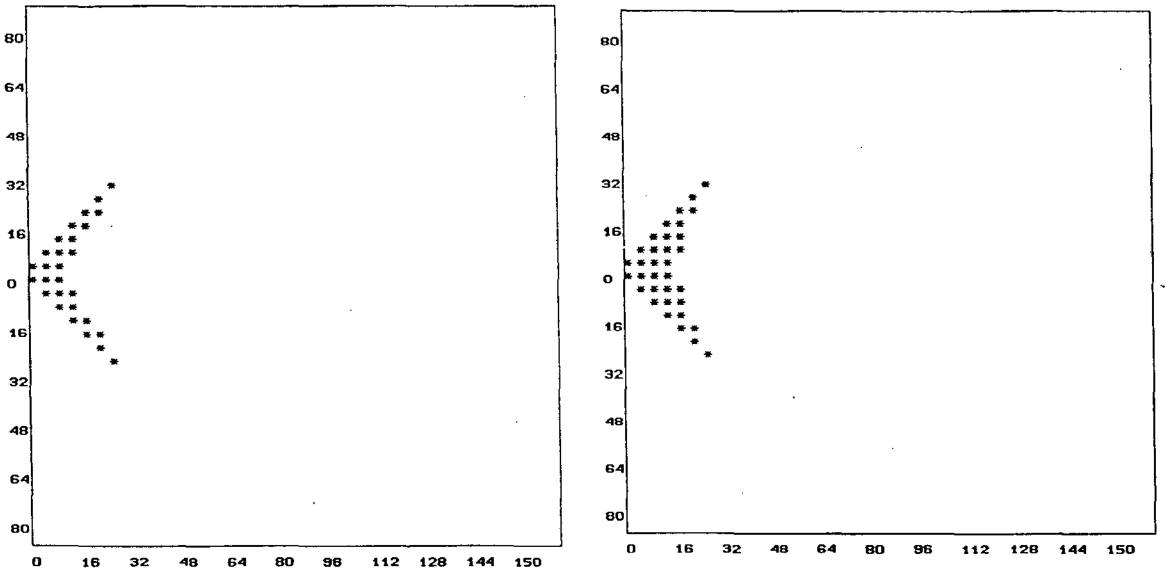
(3.4) Simulation results using shortest distance model

In this section we are going to present the simulation results for the mobility patterns of *MS* as specified by $P_L, P_{D1}, P_S, P_{D2}, P_R$ using the shortest distance model. Since the *MS* enters the *LR* area from the west direction, we have taken *MS* entering into the *LR* area into the cell having coordinates *(0,0)*. figures 13,14,15 shows the *MS* mobility patterns for different probabilities, and the dots in these figures are equal probability areas with respect to the values of $P_L, P_{D1}, P_S, P_{D2}, P_R$



$P_L = 0.2, P_{D1} = 0.2, P_S\ 0.2, P_{D2} = 0.2, P_R = 0.2$

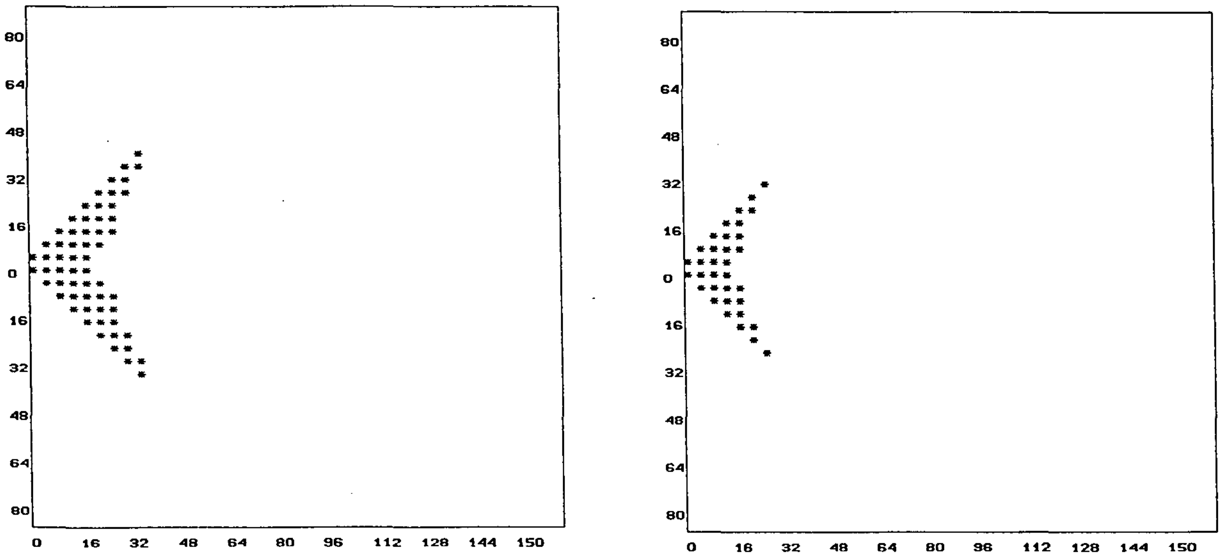
$P_L = 0.2, P_{D1} = 0.25, P_S = 0.1, P_{D2} = 0.25, P_R = 0.2$



$P_L = 0.3, P_{D1} = 0.1, P_S = 0.2, P_{D2} = 0.1, P_R = 0.3$

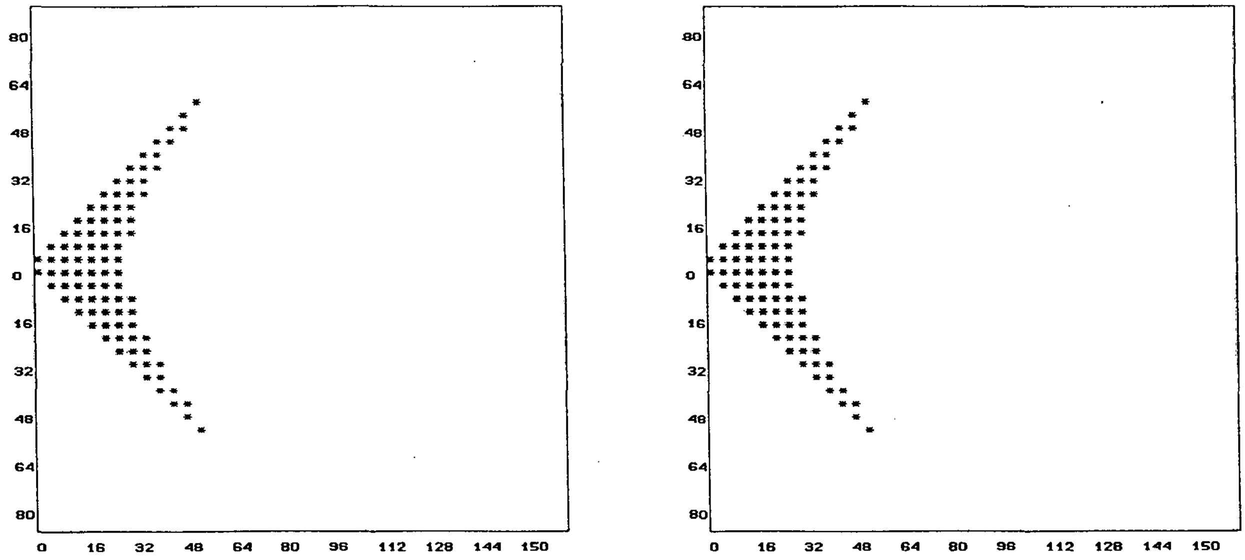
$P_L = 0.1, P_{D1} = 0.25, P_S = 0.3, P_{D2} = 0.25, P_R = 0.1$

Figure 13. *MS* mobility patterns for equal probability contours of 0.009



$P_L = 0.2, P_{D1} = 0.2, P_S = 0.2, P_{D2} = 0.2, P_R = 0.2$

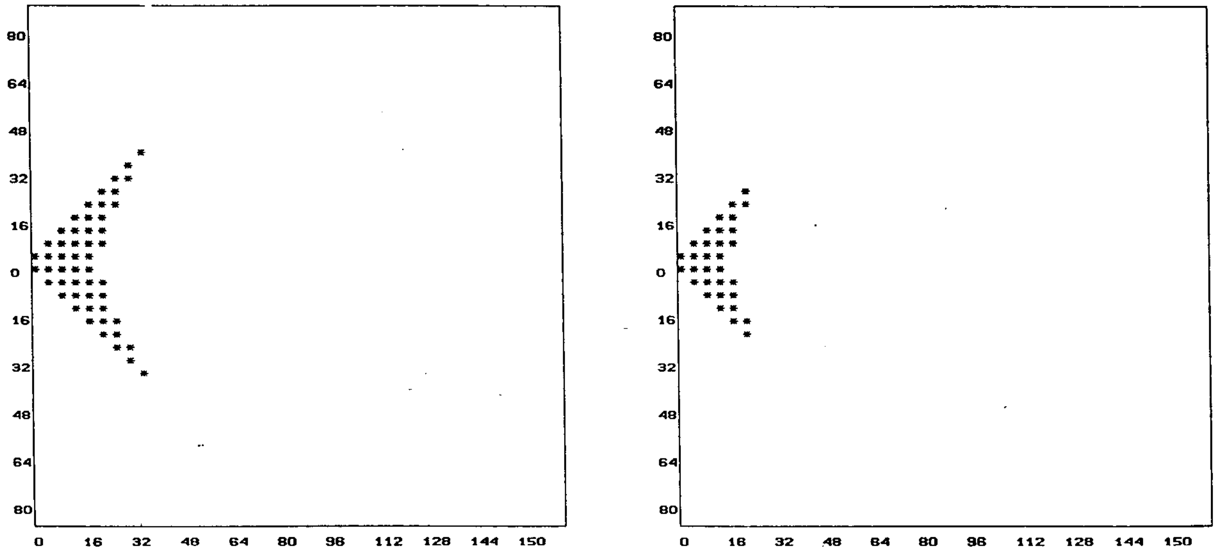
$P_L = 0.2, P_{D1} = 0.25, P_S = 0.1, P_{D2} = 0.25, P_R = 0.2$



$P_L = 0.3, P_{D1} = 0.1, P_S = 0.2, P_{D2} = 0.1, P_R = 0.3$

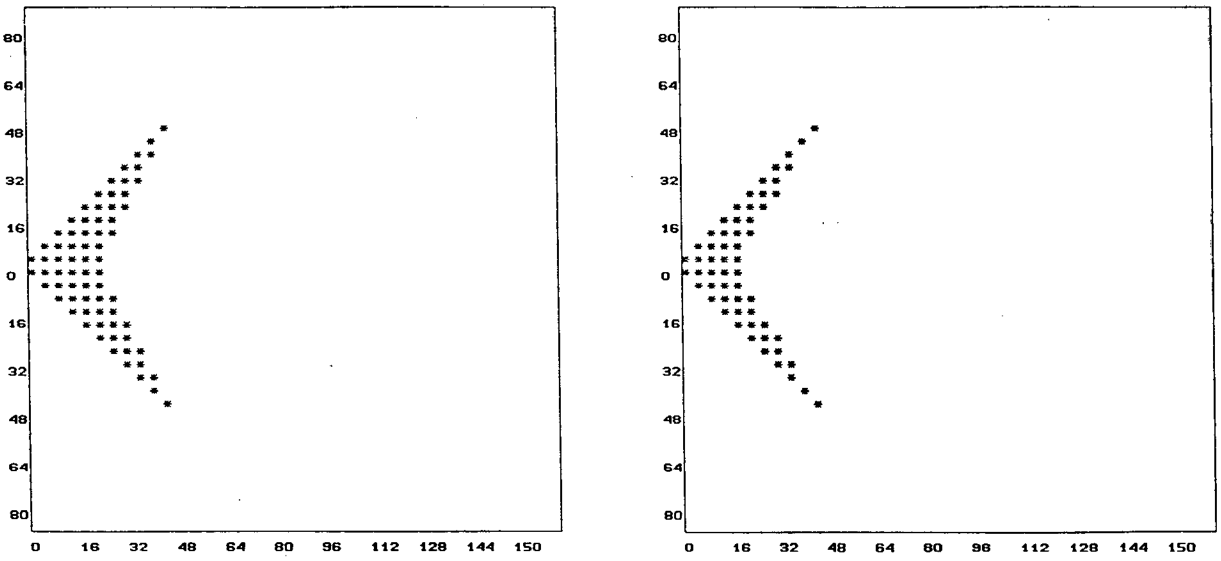
$P_L = 0.1, P_{D1} = 0.25, P_S = 0.3, P_{D2} = 0.25, P_R = 0.1$

Figure 13. *MS* mobility patterns for equal probability contours of 0.0005



$P_L = 0.2, P_{D1} = 0.2, P_S = 0.2, P_{D2} = 0.2, P_R = 0.2$

$P_L = 0.2, P_{D1} = 0.25, P_S = 0.1, P_{D2} = 0.25, P_R = 0.2$



$P_L = 0.3, P_{D1} = 0.1, P_S = 0.2, P_{D2} = 0.1, P_R = 0.3$

$P_L = 0.1, P_{D1} = 0.25, P_S = 0.3, P_{D2} = 0.25, P_R = 0.1$

Figure 13. *MS* mobility patterns for equal probability contours of 0.001

Chapter 4

LU Optimization Problem

(4.1) Problem formulation and Knapsack approach to the Optimization problem:

Proper design of Location Registration area is tradeoff between *LU* traffic and paging traffic as explained in the first chapter. Generally paging traffic is less critical than *LU* traffic [4] since *LU* effects not only the radio resource, but the load on distributed location databases as well. In general paging traffic is proportional to the number of calls to all *MS*'s in a particular *LR* area. While the *LU* traffic is proportional to the number of *MS*'s crossing *LR* area borders. Prior to the planning of the design of a *LR* area network designers must collect these data as input parameters. Although obtaining these data is considerable difficulty in practice. For this we have already developed the models in the previous chapter, which are useful in our Optimization problem. Our Optimization goal is to minimize the cost of location updating with out violating the paging cost. i.e., maximize the number of cells traversed with in the *LR* area for the same paging cost. This section considers the Optimization problem, which reduces the *LU* cost by keeping the paging cost as constant.

The Optimization problem is given by

$$\text{Maximize} \quad N_K(X) = \sum_{i=1}^{m}\sum_{j=1}^{m} C_{ij}(X)$$

$$\text{Subject to} \sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} = k \tag{29}$$

where $X = [x_{ij}]_{m\times m}$ is the binary $m \times m$ matrix representing the cell assignments of the *LR* area, i.e., it represents the shape of the *LR* area, *K* is the number of cells in *LR* area, N_K is the expected number of cells the *MS* traversed in an *LR* area of size *K*. and is the function of *X*, which we have derived in the previous chapter and is given by

$$N_K = \sum_{(i,j)} dist \Pr(e(i,j))$$

where *dist* is $|i-a|+|i-b|+|i-j| = n$ if $i<j$

$|j-a|+|j-b|+|j-i| = n$ if $i>j$ for any cell (i,j), (a,b) is the coordinates of starting *LU* cell and $\Pr(e(i,j))$ is the probability that (i,j) is the last cell before exiting the *LR* area and is given by

$\Pr(e(i,j)) = x_{i,j}\big(E(i-1,j)\,\bar{x}_{i-1,j} + S(i,j+1)\,\bar{x}_{i,j+1} + N(i,j-1)\,\bar{x}_{i,j-1} +$

$W(i+1,j)\,\bar{x}_{i-1,j} + SE(i-1,j+1)\,\bar{x}_{i-1,j+1} + SW(i+1,j+1)\,\bar{x}_{i+1,j+1} +$

$NW(i+1,j-1)\,\bar{x}_{i+1,j-1} + NE(i-1,j-1)\,\bar{x}_{i-1,j-1}\big)$ for any cell (i,j) on the boundary of the *LR* area and $C_{ij}(X)$ is the cost associated with each cell (i,j) and is given by

$$C_{ij}(X) = dist \Pr(i,j) \qquad (30)$$

If we take the *X* as independent then the Optimization problem (29) becomes the knapsack problem. Since the knapsack problem is *NP-Complete*. Then the Optimization problem given in (29) is also *NP-Complete.* Following is the procedure for the Knapsack Optimization of our problem.

There is a distinction between problems whose solution is by a polynomial time algorithm, and the algorithms which can not be solved in polynomial time. The problems which can be solved using the polynomial time include sorting which can be solved in $O(n\log(n))$ time, searching $O(\log(n))$ and matrix multiplication $O(n^{2.81})$. The best known examples which can not be solved in polynomial time include travelling salesman problem $O(n^2\,2^n)$ and Knapsack problem $O(2^{n/2})$. To develop efficient algorithms no one has been able to develop a polynomial time algorithm for any group in the non-polynomial group. The theory of *NP-Completeness* does not provide a method of obtaining polynomial time algorithms for problems in the non-polynomial group [31]. , A problem which is *NP-Complete* will have the property that it can be solved in polynomial time iff all *NP-Complete* problems can be solved in polynomial time. In order to determine whether the knapsack problem is *NP-Complete* or not we have to know about whether it is deterministic or non-deterministic one. In the deterministic case the algorithms has the property that the result of every operation is uniquely defined. Such a programs agrees with a way how the programs are executed in a computer. In theoretical framework we can not put any restriction on the outcome on every operation. We can allow algorithms whose outcome is not uniquely determined but limited to specific set of outcomes. The machine executing the algorithm can choose the outcomes subjected to the termination condition. This leads to nondeterministic algorithms. To specify this type of algorithms we are considering one new function and two statements.

(i)	Select (G)	: Arbitrarily chooses one of the cells from set G.
(ii)	Failure	: Signalling for unsuccessful completion.
(iii)	Success	: Signalling for success completion.

The assignment statement $x_{i,j} \leftarrow$Select (0,1) would result in $x_{i,j}$ being assigned to one of the integers in the rage [0,1]. There is no rule in specifying how this choice is made. The failure and success signals are used to define the computation of the algorithm. These are statements are like a stop statements and cannot be used to effect a return. Whenever there is a set of choices that lead to the successful solution, then one such set is made to lead to successful completion. A non-deterministic algorithm terminates unsuccessfully if and only if there is no specific set of choices leading to a successful signal [30]. The computation time of these choices are $O(1)$. A machine capable of executing a non-deterministic algorithm in this way is called a non-deterministic machine. Applying unbounded parallelism can make deterministic version of nondeterministic algorithm in computation. Each time whenever the algorithm made a choice, it itself make several copies of itself. One such copy is made for each of the several choices. The copy that made a successful solution made all the other computations to terminate. The above interpretation may enable one to better under stand the non-deterministic algorithms. It is possible to construct the nondeterministic algorithms for which many choice sequences lead to success completion. The Knapsack decision problem is to determine if there is a 0/1 assignment of values to $x_{i,j}$ $1 \le i \le m, 1 \le j \le m$ such that $\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} = k$. The time that is required for the *nondeterministic* algorithm is the minimum number of steps to reach successful solution. Following is the nondeterministic polynomial time Knapsack problem for the Optimization problem (29)

```
            Procedure NDPK ($K$, $X$)
    ( $K$ is the number of cell with in the $LR$ area, $X$ is the binary $m \times m$ matrix
represent the cell assignments of the $LR$ area whose initial values are 0)
            Begin
                For index1 ← 1 to m
                Begin
                    For index2 ← 1 to m
                    Begin
                        $X$ [index1][index2] ← Select (0,1);
                    End for;
            End for;
            if ($\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} = k$) then success.
                        else failure.
            End if;
            End NDPK;
```

From the above algorithm, Select (0,1) assigns to X [index1][index2], $1 \le index1 \le m$, $1 \le index2 \le m$. if ($\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} = k$) then success else failure, checks to see if this constraint is feasible. A successful termination is possible iff the answer to the decision problem is yes.

(4.2) Greedy Approach for the Optimization problem in the design of the *LR* area

This is the best approach to solve for Optimization problem. This approach is one of the most straightforward technique and it can be applied to wide variety of different problems. This approach considers Optimization problem (29) having K inputs and requires us to obtain a subset to satisfy the constraint $\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} = k$ is called feasible solution i.e., Optimum design of the *LR* area. We are required to find out the feasible solution which maximizes the given objective function $N_K(X) = \sum_{i=1}^{m}\sum_{j=1}^{m} C_{ij}(X)$. We are giving an algorithm (later in this section) based on this greedy approach which works in stages, considering one cell at each stage. At each stage a decision is made from the set of cells whether that particular cell selected is optimal one or not. This is done by considering cells in an order determined by selecting those cells that are closer to the previous cell. If the inclusion of the next cell into the partially constructed *LR* area will result in an infeasible solution, then this input not added to the partial solution. This selection procedure itself is based on some Optimization measure. This measure may or may not be the objective function. Following is the control flow how the greedy approach works.

```
Procedure GREEDY (LU, K)
{LU is the array, which initialises the assigned cells in which maximum of K
cells are selected}
Begin
        Optimum_LR area =  {$\phi$}
        Repeat
                Index_pointer=0;
                Index_cell = Selection_cell (LU);
                If (Optimum (Optimum_LR_area, Index_cell)
                Begin
                        Optimum_LR_area = Optimum_LR_area $\cup$ Index_cell;
                End if;
                Index_pointer = Index_pointer + 1;
        Until (Index_pointer  <= k);
End GREEDY;
```

From above control flow Index_pointer is the index that is used as the index while selecting the cells, Selection_cell selects an input from *LU* each time and assigns this value to Index_cell. Optimum_LR_area is a Boolean function which determines whether if Index_cell can be inserted into the Index_cell vector or not. $\cup$ is the union which actually combines the Index_value with the previously obtained Optimum_LR_area to update the Optimum_LR_area. Using this approach more complex problems can be solved. One of such is the knapsack problem which is explained in the previous section. Following is the algorithm for the greedy Approach. This approach designs a *LR* area that satisfies the Optimization problem (29)

Algorithm

step 1 Select the starting *LU* cell (a,b) and assigned that cell. i.e., select that cell in the LR area .Initialize all the variables defined above in the control flow. $x_{a,b}=1$, Index_pointer=1, Optimum_LR_area = $\{(a,b)\}$,

Optimum $N_n(x)$=1,Optimum $N_n(x)$ is the optimum value of the $N_n(x)$ found by the equ (29).

step 2 Set the index pointer to one. Which gives the number of cells that are already assigned in the *LR* area. This pointer is incremented at each iteration until the *LR* area contains *K* Cells. Since the *LR* area constructing contains *K* cells only from our Optimization problem (29).

Index_pointer = Index_pointer+1;

step 3 Select all the cells that are adjacent to the lastly selected $(x_{\text{new}}, y_{\text{new}})$ cell into an array Index_cell. $(x_{\text{new}}, y_{\text{new}})$ is the previously selected *LU* cell.

Index_cell(x)={(α,β) / $x_{\alpha,\beta}$ = 1and $x_{\alpha-1,\beta+1}=1$ or $x_{\alpha,\beta+1}=1$ or $x_{\alpha+1,\beta+1}=1$ or $x_{\alpha+1,\beta}=1$ or $x_{\alpha+1,\beta+1}=1$ or $x_{\alpha,\beta-1}=1$ or $x_{\alpha-1,\beta-1}=1$ or $x_{\alpha-1,\beta}=1$ }

step 4 In this step we are founding the optimum cell from the set Index_cell (x). following this procedure for finding the optimum value .

```
        For each $(\alpha,\beta) \in$ Index_cell $(x)$,
        let $x_{\alpha,\beta}=1$;
        If ( $N_n(x) >$ Optimum $N_n(x)$ ) Optimum $N_n(x) = N_n(x)$;
        $(x_{new}, y_{new}) = (\alpha,\beta)$;
        $x_{\alpha,\beta}=0$;

step 5  Repeat the step 4 $\forall(\alpha,\beta) \in$ Index_cell $(x)$,

step 6  The newly selected cell is added to Optimum_LR area and assign the cell
        Optimum_LR _area $\leftarrow (x_{new}, y_{new})$;   $(x_{new}, y_{new})=1$

step 7  Go to step 2 until Index_pointer $<= K$
```

The Optimum_*LR* _area list contains the cells in the order as proceeded by the above algorithm. After the algorithm is over the Matrix $X=[x_{ij}]_{m\times m}$ gives the shape of the Optimum *LR* area. The exact shape and dimensions of the *LR* area is such that it should satisfy the location tracking of each individual *MS* and it should satisfies the following conditions [3].

(1) When a call for the mobile user comes then the Base Station page these calls into the correct cells where the *MS* is currently rooming.
(2) Whenever the *MS* moves out of the vicinity of the *LR* area, the *MS* itself takes a decision whether to update or not.

The *LR* area shapes obtained using this approach depend on the mobility patterns of *MS* and the shape of the *LR* area in terms of the incoming call rate. The smaller the incoming call rate the larger the size of the *LR* area to keep the paging cost per unit time the same. The mobility patterns of *MS* depend on the traffic characteristics in that region. Thus the *LR* shapes obtained for the same paging constraint are different, since the mobility movements of *MS* are different in different directions. In order to agree for the ideal conditions the system and the *MS* has to agree for the size and shape of the *LR* area. Here are the three approaches for the ideal conditions as given by A.Abutaleb and V.O.K.Li [4]

(1) The system and the *MS* has to store different numbered lists for various mobility models, Optimum_LR_area in our algorithm. So that when the *MS* performs the *LU* the system specifies the number from the list i.e.,Optimum_LR_area representing the mobility models of the *MS* in the *LR* area. The main disadvantage with this technique is the system has to maintain large database.

(2) In this approach whenever the *MS* performs the *LU* the system gives the set of Optimum_LR_area groups to the *MS* based on which direction *MS* is moving.

(3) Since the *LR* area obtained using the greedy algorithm is irregular, approximate these irregular shapes with the regular shapes as given by the Optimization problem in the next section.

(4.3) Optimal rectangular Optimization problem and comparison between various Optimization methods.

In order to agree for the correct shape and size of the *LR* area between MS and the system an Optimal rectangular Optimization problem is presented in this section. The Optimization problem for the Optimum rectangular *LR* area shape is given below [3].

$$\text{Maximize} \quad N_K(X) = \sum_{\alpha=1}^{m}\sum_{\beta=1}^{m} C_{\alpha\beta}(X) \qquad (31)$$

$$\begin{aligned} \text{Subject to } x_{\alpha\beta} = 1 \quad & \forall\alpha \in \{i',\ldots, i'+l-1\} \\ & \quad \text{where } i' \in \{1,\ldots, m-l+1\} \\ & \forall\beta \in \{j',\ldots, j'+w-1\} \\ & \quad \text{where } j' \in \{1,\ldots, m-w+1\} \end{aligned}$$

and $l\,w = k$. where k is the number of cells in the *LR* area.

all the parameters in this Optimization problem are already explained in the first section of this chapter. The solution to this Optimization problem can be found by complete enumeration. And now coming to comparison between the three different approaches, mobility patterns of *MS* obtained using the fluid model of mobility, design of the *LR* area using the greedy approach and the Optimal rectangular Optimization problem. The Optimum rectangular Optimization shows the better performance. Since it taken into consideration the direction of travel and the mobility pattern for a specific *LR* area. Thus the Optimum rectangular *LR* areas are good approximations to the irregular *LR* areas obtained using the greedy approach as explained in the second section of this chapter. This Optimum problem (31) greatly simplifies the *LU* procedure. In this case when the *MS* performs the *LU* the system informs to the mobile terminal of the *LR* area about the length, the width and the position of the *LU* cell with in the rectangular *LR* area. For the known incoming call rate and mobility patterns of *MS* the Optimization problem (31) specifies the Optimum *LR* area shape.

Conclusions

In this dissertation work we are mainly concerned about the modelling aspects and simulation results for the design of the *LR* area using the shortest distance model of mobility. For this model we have considered the two-dimensional grid architecture. This model is more realistic than the independent identically distributed (i.i.d.) model. The model based on i.i.d is generally used for pedestrian users. *LR* area designed using shortest distance model gives information about the mobility patterns of *MS* to minimize the cost of *LU* or maximize the number of cells traversed inside the *LR* area before performing the location updating. The shortest distance model we have considered is for the vehicular *MS*. This model minimizes the cost of *LU* in comparison to generic model developed by the Abutaleb and Li [4] and it also reduces the time that is required for the *MS* in moving from one cell to any other cell in the *LR* area. Using the shortest distance model we have also derived the following

(i) The probability of moving to any cell in the *LR* area from the starting cell in minimum time.

(ii) The Optimum number of cells the *LR* area contains, which minimizes the *LU* cost.

Using (i) and (ii) we have given the *LU* Optimization problem

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